ELECTRIC VEHICLE RESEARCH, DEVELOPMENT AND DEMONSTRATION ACT OF 1975

HEARINGS

BEFORE THE

SUBCOMMITTEE ON ENERGY RESEARCH,
DEVELOPMENT AND DEMONSTRATION

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

NINETY-FOURTH CONGRESS

FIRST SESSION

ON

H.R. 5470

JUNE 3, 4, 5, 6, 1975

[No. 27]

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Committee on Science and Technology

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ELECTRIC VEHICLE RESEARCH, DEVELOPMENT AND DEMONSTRATION ACT OF 1975

TUESDAY, JUNE 3, 1975

House of Representatives,
Committee on Science and Technology,
Subcommittee on Energy Research,
Development, and Demonstration,
Washington, D.C.

The subcommittee met, pursuant to notice, at 10:12 a.m., in room 2318, Rayburn House Office Building, Hon. Mike McCormack (chairman of the subcommittee) presiding.

Mr. McCormack. The meeting will come to order, please.

I want to welcome you all here this morning.

Today we begin 4 days of hearings on H.R. 5470, the Electric Vehicle Research, Development, and Demonstration Act of 1975.

Joining me in introducing this bill last March were Congressman George Brown of California; Congressman Olin Teague, Chairman of the Committee on Science and Technology; Congressman Barry Goldwater; and Congressman Mosher, ranking minority members of the subcommittee and the full committee respectively; as well as, 61 additional Members of Congress who have composed this legislation to date.

In addition to that, and he will comment in a minute, Congressman Ottinger has also submitted similar legislation, which he will discuss before we start.

As you know, the primary thrust of this bill is the accomplishment of a practical demonstration of the feasibility of electric cars. A significant fraction of our personal transportation needs, particularly those which are now being met by "second" cars, are for use primarily inside our cities throughout the country.

The development and commercialization of electric vehicles is of critical importance at this time, for it could make an enormous impact on our growing dependence on imported petroleum, and virtual elimination of urban auto pollution and noise are obvious by-products.

The program called for in the bill would be set up within ERDA, and it would address all aspects of electric vehicle transportation through a 3-year research, development, and demonstration project. The project would include a two-phase demonstration program involving 10,000 electric vehicles operating in every region of the country. This program is modeled somewhat after the Solar Heating and Cooling Act of 1974, which had a similar goal: the rapid implementation of a developing technology which has a very significant potential for impacting on our energy or fuel supplies. As with solar heating and cooling, electric vehicle technology is already at the point where it is capable of meeting a large fraction of our needs: electric cars existing today are already adequate for well over 90 percent of the trips made in this country without recharging, and we saw a number of them this morning down in the Rayburn Horseshoe.

The research and development under this legislation would include work on advanced energy storage systems for vehicles, such as, obviously, various types of batteries, as well as control systems and overall design, with the aim of reaching maximum efficiency, durability, ease of repair, and recyclability of parts. Associated studies would focus on urban design and traffic management for optimum transportation energy use and minimum environmental impact. The consequences of these technological studies in the physical and social sciences, as they relate to personal transportation should lead to vital progress toward future vehicles, where we may expect perhaps 200 miles between charges, plus optimal systems for battery charging and replacement and advanced energy-effective compound propulsion systems.

Before turning to these hearings, I would like to express my appreciation to the Electric Vehicle Council for their exhibition today of about 20 electric vehicles down in the Horseshoe, which many of you saw, and I presume many of you were participants in that display. It provided a convincing demonstration that technology for electric vehicles is here, ready to attack our problems which arise from reliance on imported petroleum.

At this time I would like to ask Congressman Ottinger, who has not only cosponsored this legislation but he has also introduced legislation, parallel legislation, of his own. During the next 4 days hearings on this legislation, we will obviously be hearing on both bills at once, and out of these hearings we hope to make such modifications as may be suggested and approved by the committee to the bill, so that we can mark up a clean bill and report it out in the very near future.

So I would like to ask at this time Congressman Ottinger to describe his bill for us.

Mr. OTTINGER. Thank you, Mr. Chairman.

I want to acknowledge your pioneering efforts in the field of propulsion of vehicles with noncombustion systems that are an alternative to the internal combustion gas engine. This is something I have been interested in for a long time.

In 1967 we demonstrated a silver-zinc batteried electric car that did get 200 miles at that time to the charge and went about 60 miles an hour.

There's no question in my mind that this technology is here today, and can be used. What we did was just expand on the fine work that you did in your legislation, and include steam cars which have a great deal of promise also as alternative vehicles for saving fuel and eliminating pollution, and hybrid cars that would use both minimal amounts of gasoline in a gasoline engine and combine it with other forms of propulsion.

At the present time there is being developed a car in Ohio that combines the best features of the electric car with the best features of the internal combustion engine, using the electric engine to get from zero to about 30 miles per hour, in its most efficient performance, and then you go automatically to using the gasoline engine. Of course, the gasoline engine uses the most gasoline accelerating from zero to up over 30 and relatively little gasoline to stay at the higher speeds. So you could combine the best features of both, and have the gasoline engine, charge the electric batteries, so you won't have the problem of plugging in the car at the same time. So we thought this ought to be included.

The only other difference in the legislation is that we have included additional protection for small business because so much of this development has been done by individual entrepreneurs or small companies that were involved in allied fields. We did not feel that the big companies ought to walk away with a disproportionate share of the funds, and the people who have worked so hard ought to not only be recognized but allowed to develop further the very significant developments that they've made in this field. We also, therefore, give specific preference in the bill to people who have had substantial experience in developing electric cars.

But I'm very glad to join with you in this effort, and I certainly thank you very much for having these hearings and pushing ahead on legislation that I think will be of great importance to the country.

Mr. McCormack. Thank you, Congressman Ottinger.

Mr. Goldwater, I think you have a statement.

Mr. Goldwater. Thank you, Mr. Chairman.

I am particularly pleased that we are beginning a week of hearings today on the Electric Vehicle Research, Development, and Demonstration Act of 1975, H.R. 5470. As a cosponsor of H.R. 5470 with several other distinguished colleagues on the Science and Technology Committee, I am acutely aware that it is imperative that the United States make a timely start to modify the fuel use patterns in our transportation sector, particularly automobile fuel usage.

Automobiles consume over one-eighth of all the energy used in the United States today. And of equal importance, automobiles and the transportation sector generally, currently use petroleum-based fuels. As we all well know, this heavy demand for petroleum has resulted in an unacceptable dependence on foreign, cartel-controlled oil and a resulting outflow of U.S. dollars to pay for the cartel-priced oil imports. Breaking this dependence and reversing the dollar outflow are absolute necessities for our national security and economic well-being. H.R. 5470 can make the timely start in this area, as other bills introduced by this subcommittee in geothermal R. & D., solar heating and cooling demonstration, and solar R. & D. have.

But to make that start not only timely, but also intelligently and effectively, we require significant input from the public, the executive branch and particularly the private sector. I am pleased that these hearings will include testimony from each of these groups. I am particularly pleased that we will be hearing from all sides of the private sector most interested in and potentially affected by this bill—the electric vehicle and automotive industry—from the smallest to the largest.

I have received literally scores of letters and brochures and prospectuses from individuals and firms who are now, or are genuinely interested in, entering the electric vehicle business. Let me express at this point appreciation for the fine assistance of that industry's association, the Electric Vehicle Council, in the preparation of these hearings, their assistance to the subcommittee in the past, and, of course, the fine demonstration of electric vehicles here this morning. The letters and inputs from the council and others, including some testifying this week, indicate, however, that there is far less than unanimous agreement on H.R. 5470, as drafted, within and outside the industry. Significant issues exist in the areas of types of demonstrations, the timing of demonstrations, procedures for industry participation, protection of small businesses, institutional constraints the state of existing electric vehicle technology, and an effective Government-management concept. We must particularly insure that we don't prematurely move too fast and thereby suffer unnecessary failures in demonstration, with resultant negative impact on the motoring public.

But, gentlemen, move we must, and move we will, in making a timely, intelligent, and effective start in modifying current fuel patterns in the transportation sector.

In my own district, the Los Angeles area, electric vehicles can make a significant difference, perhaps as early as 1980. A recent EPA study concluded that, at a minimum, electric vehicles with existing technology could replace a million second cars in Los Angeles in 1980, 17 percent of all area cars "with little sacrifice in typical daily driving patterns." Electric vehicles with advanced technology could constitute from 45 to 75 percent of all cars in Los Angeles in the 1990–2000 time frame, depending on supporting facilities. The obvious environmental benefits, as well as the resulting petroleum savings, clearly support our consideration of a timely demonstration of this electric vehicle potential.

That this subcommittee is genuinely dedicated to fully developing that potential should not be doubted. To support this and other promising projects, we have increased the ERDA 1976 authorization request by more than $35 million in the energy storage systems and advanced transportation power systems programs, more than doubling the requests. With H.R. 5470, we intend to parallel those advanced R. & D. efforts with an early demonstration of the electric vehicle's potential contribution, as documented in the EPA study of Los Angeles. The assistance of our witnesses will be instrumental in shaping the demonstration intelligently and achieving early acceptance of the electric vehicle. Electric vehicles will have an accepted place in Los Angeles transportation and in communities across the Nation as a result of these efforts.

Thank you, Mr. Chairman.

Mr. McCormack. Thank you, Mr. Goldwater.

I would like to now pay my respects to Congressman Brown, who has done a good deal of work on this subject as chairman of the subcommittee last year, and I'd like to defer to Congressman Brown for his statement.

Mr. Brown. Thank you, Mr. Chairman.

Mr. Chairman, I'd like to move for unanimous consent to have my statement included in the record.

Mr. McCormack. Thank you, Mr. Brown.

[The statement of Mr. Brown is as follows:]

STATEMENT OF GEORGE E. BROWN, JR., AT THE OPENING OF HEARINGS OF H.R. 5470, THE ELECTRIC VEHICLE RESEARCH, DEVELOPMENT AND DEMONSTRATION ACT OF 1975

It has been a pleasure to work with Chairman McCormack in the preparation of this legislation, and I find it an exciting prospect to be starting out today in the process which may result in the first major forward step in our transportation technology in more than fifty years.

One of the less obvious needs this legislation deals with is the difficulty our society seems to have in translating our vast technological potential into measures which improve our lives. Once we've set up a pattern of doing things, there seems often to be overwhelming barriers against improvement, even though opportunities are obvious. As in the Solar Heating and Cooling Act of 1974, we are trying here to break through these barriers by providing incentives and federal leadership aimed at getting a ready technology into production and use. There are many opportunities for developments in transportation beyond electric vehicles, of course, and I hope that the action of the Science and Technology Committee in mandating a large research and development program in this area in the ERDA budget authorization process will help us pursue a wide range of these opportunities.

Similarly, the legislation studied last year by this Committee, and which I reintroduced this Session (H.R. 5557, the "Ground Propulsion Systems Research, Development and Demonstration Act") in which NASA would be given an explicit authorization for work in ground transportation, is another step to a broad transportation program. But the legislation before us today can provide a cutting-edge to progress in all the areas of transportation technology, by providing a demonstration that a particular development, with proper goals and incentives, can be implemented now to the benefit of individuals and the country as a whole. The measures in the Electric Vehicle Research, Development, and Demonstration Act will get us started on reducing the air pollution which plagues our cities, and in reducing our dependence on liquid fuel, which is crippling our economy.

I want also to emphasize the planning and urban design studies which we have written into this legislation. Just as electric vehicles are a small part of transportation technology, transportation itself is just one aspect of urban design technology.

It is time we take a step back from our blind random sprawl in living patterns, and begin to think about better ways to organize our living and commerce, so that all our citizens can have pleasant surroundings and reasonable access to their places of work and recreation. We've required in this bill that the Administrator of the Energy Research and Development Administration study the energy consumption and pollution implications of current urban and transportation design patterns, and that he recommend ways of removing institutional barriers against more rational planning. His findings would be reported to the Congress, and we would hope then to have a framework for further legislation in this area if it is needed.

Mr. McCORMACK. Mr. Mosher, I think you had a motion you wanted to make.

Mr. MOSHER. Thank you, Mr. Chairman.

I move for unanimous consent that the statement of Dr. Wakefield be inserted in the record of the committee's hearings at this point.

Dr. Wakefield is originally a product of my district, and I think his statement is important, particularly with the emphasis it places on the means for judging electric vehicles. I think it's a very practical approach.

Incidentally, Mr. Chairman, Dr. Wakefield and I come from the Milan, Ohio area, where Mr. Edison was born and raised, so we have a sort of an ingrown, inborn reason for being particularly interested in this development of the electric automobile.

Mr. McCormack. Thank you, Mr. Mosher.

There being no objection, the statement of Dr. Wakefield will be inserted in the record at this point, and members will be provided with a copy.

STATEMENT OF ERNEST H. WAKEFIELD, PRESIDENT, LINEAR ALPHA, INC.

[The complete prepared statement of Dr. Wakefield is as follows:]

3 June 1975

STATEMENT TO THE SUBCOMMITTEE ON ENVIRONMENT AND THE ATMOSPHERE

of the

HOUSE OF REPRESENTATIVES

by

DR ERNEST H WAKEFIELD, PRESIDENT, LINEAR ALPHA, INC

I am Dr Ernest H Wakefield, President of Linear Alpha, Inc. I have a doctor's degree in electrical engineering from the University of Michigan, and for 24 years have been president of companies manufacturing large, complex electronic equipment.

COMPANY EXPERIENCE

Seven years ago our company began designing and building electric vehicles utilizing full size (Ford and Dodge) vans, and more recently, compact (Ford Pinto) type automobiles. The Company has also designed an advanced electric vehicle for the Energy Research and Development Administration, ERDA, in which the lithium-sulfur battery was postulated. For this same group we are currently delivering passenger electric LinearVans. We have also assembled both AC and DC electrically powered vehicles, and are currently manufacturing DC powered electric LinearVans, and Seneca Electric Vehicles, illustrated in the enclosure. These electric vehicles are distributed through Dodge and Ford dealers, respectively. Both types of electric vehicles were developed as optimized systems, utilizing computer technology, by Dr. Gordon J. Murphy, Professor of Electrical Engineering at Northwestern University. With their long history of development and testing, these vehicles represent a high level of personal electric ground transportation. And until better batteries are available, which could then be placed aboard, these vehicles, it is believed, will be only incrementally improved.

CHARACTERISTICS OF THE LINEARVAN AND THE SENECA

Both the LineaerVan and the Seneca Electric Vehicles can operate at speeds up to 60 mph. In actual practice, in urban driving, with stops and accelerations, the LinearVan requires 0.8 kilowatt hour per mile, while the lighter Seneca consumes about one-third kWh per mile. The drive system of these vehicles is about four times more efficient than that of the gasoline powered equivalent vehicle. In addition, when the electric vehicle halts for any reason essentially no power is consumed.

The LinearVan, depending on the model chosen, will carry a useful load of from 750# to 2700#. The LinearVans for ERDA will mount positions for 13 passengers beside the driver. Acceleration of each vehicle is comparable with the gasoline vehicle counterpart. The range in urban driving for the LinearVan is about 30 miles. With the vehicle continuously exposed to outside temperatures, the range in Chicago between winter and summer has been found to be ± 15 percent. The range of the Seneca exceeds the LinerVan. For convenience, and to enhance the daily range, each vehicle is equipped with an on-board charger and cable terminated with a 230 volt 30 ampere male plug requiring the same receptacle as for the home clothes drier.

MAINTENANCE

The absence of moving parts in solid state controls, the known trouble-free life of electric motors, the lack of moving elements in the charger, three major modules of our electric vehicles, have contributed to the observed low maintenance found in practice -- no faults in over 17 months of daily service. In regards to battery watering, 25 miles of urban and high speed driving a day has necessitated water addition once ever 7 - 8 weeks. Life of the battery is continually being tested, and in usual operation is expected to last several years, being a function of watering and depth of cycles. Maintenance discussed, how may the quality of an electric vehicle be determined?

MEANS OF JUDGING ELECTRIC VEHICLES

In contemplating the purchase and use of an electric vehicle one may make an evaluation as follows:

Question	Answer
1. Will it fullfill the task?	1. In urban use 96 percent of trips are less than 20 miles*.
2. Will it satisfy my need?	2. A subjective question. Consider speed, range, drivability, servicibility, quality of manufacture.
3. How much can I afford to pay for an electric vehicle on a purely economic basis?	3. See Fig 1. One can afford to pay 2 - 3 times the cost of the equivalent gasoline powered vehicle.
4. Other factors influencing my choice?	4. Ecology, freedom from fumes and noise, the challenge of an alternate type of ground transportation.

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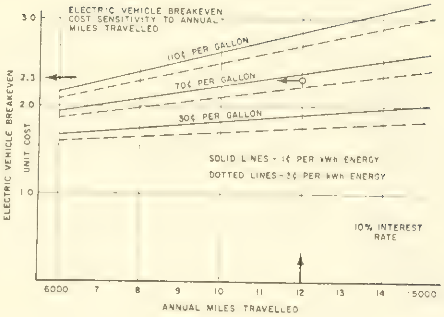
*Electric Vehicle Council Report, May 1971.

HOW MUCH CAN I AFFORD TO PAY* FOR AN ELECTRIC VEHICLE?

Fig. 1.



1. Determine the miles you would drive per year in an electric vehicle.
2. Find the price you pay per gallon of gasoline.
3. Know the incremental cost of electric energy per kilowatt-hour.
4. From this point travel left on the graph until the "unit cost" line.
5. Multiply the interpolated "unit cost" number by the completely optioned price of the gasoline powered vehicle.

For example:

Assume 12,000 miles per year, 70 ¢ per gallon gasoline, 2 ¢ per kilowatt-hour electric energy.

From the number 12 on the bottom line, rise vertically until the intersection of the solid line "70 ¢ per gallon." Travel horizontally to the left until the "unit cost" line is reached. The interpolated number is 2.3. Assume the fully optioned Ghia is $5,890.

Therefore: I can afford to pay on a purely economic basis 2.3 x $5,890 or $13,547 for the electric Mustang Ghia.

**From paper presented at the Third International Conference on Electric Vehicles, 1974.*

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5. Comfort and appointments?	5. Qualities similar to an IC vehicle would be rated excellent.
6. Availability of options?	6. Options similar to an IC vehicle would be rated excellent.

While the above questions and answers are qualitative, below is quantitative information believed true for full-sized electric vehicles in 1975:

QUANTITATIVE JUDGEMENTS ON ELECTRIC VEHICLES

For a person seeking a full-sized electric vehicle, what should be his criteria?

Parameter	Assessment
1. Speed.	1. 55 - 60 mph is excellent.
2. Acceleration.	2. 0-30 mph in 10 sec. is excellent.
3. Range in urban driving.	3. 30 - 40 miles is excellent.
4. Control of power to motor.	4. Best quality is solid state chopper control. Lesser quality is contactor, or resistance control.
5. Charger.	5. Best quality is electric isolation and timer plus taper control.

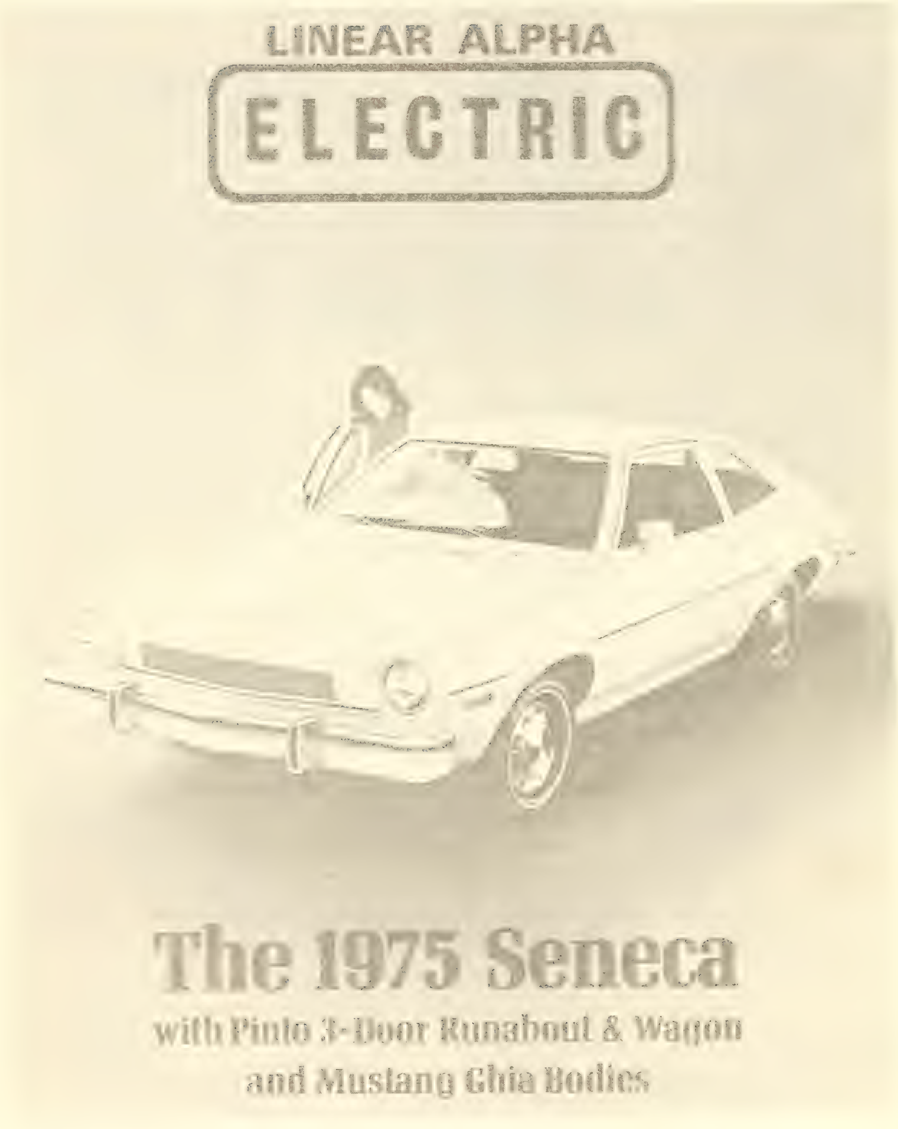
PRODUCTION ABILITY OF LINEAR ALPHA, INC. AND FINANCING TERMS

Currently Linear Alpha, Inc is in small production of both electric LinearVans and Seneca Electric Vehicles in the Chicago area. The Company could, the first year, increase its production rate to 1500 vehicles per year, and in two years be producing at the rate of 5000 vehicles per year. Stressing freight charges, the Company, with more substantial production, would consider location of its production plants adjacent to existing automotive production lines.

Both the electric LinearVan and Seneca Electric Vehicles are eligible for floor-plan financing. Under such conditions a qualified dealer can stock a Company electric vehicle in his show room paying only carrying charges to the bank or finance company.

CONCLUSIONS

High performance electric vans and passenger vehicles, designed for urban travel, comfortably appointed, are in routine production by Linear Alpha, Inc. Distribution of these vehicles is through Dodge and Ford dealers, respectfully. The worthiness of the vehicles is recognized by the banks as being eligible for floor-plan financing. Because of the highly efficient drive train of these electric vehicles and their low maintenance cost, one can afford to pay a substantial premium for LinearVan and Seneca Electric Vehicles. Finally, the enanctment of HR 5470 will serve to stimulate the electric vehicle industry, reduce inventory of Detroit IC vehicles, create new jobs, restrict energy use, and serve to cleanse the atmosphere and reduce the noise in our cities. In addition, it will show the world that American inventiveness is still a noble and active national trait.



LINEAR ALPHA

ELECTRIC

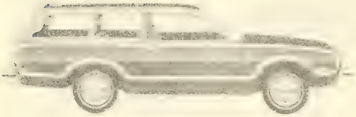
The 1975 Seneca

with Pinto 3-Door Runabout & Wagon
and Mustang Ghia Bodies

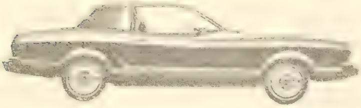
1975 Seneca body styles

Pinto 3-Door Runabout

Pinto Wagon



Pinto Wagon With Squire Option



Mustang Ghia

Measurements	3 Door Runabout	Wagon	Ghia
Wheelbase	94.4"	94.7"	96.2"
Length	169.0"	178.8"	[illegible]
Height	50.3"	52.0"	50.0"
Width	69.4"	69.7"	70.2"

Available from selected Ford dealers.

VEHICLE SPECIFICATIONS

Cruising speed	40 mph
Approximate range attainable in urban driving in an 8 hour day	70 miles
Approximate range on a single charge at 25 mph with radial tires at 30° F.	50 miles
Motor	Electric
Controls	Solid state electronics
Energy source	Battery
Charging system	On-board charger operating from 120 V 15 amp outlet
Propulsion system	Linear Alpha, Inc.
Vehicles (body styles)	3-Door Runabout Wagon Mustang Ghia

PARTIAL LIST OF OPTIONS

Nearly all Ford options can be provided

Steel-belted radial tires

Gasoline heater

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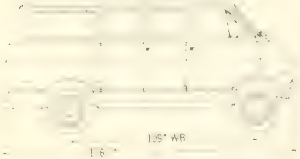
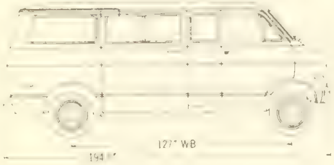
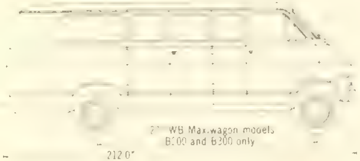
LINEARVAN – ELECTRIC VEHICLES Sold and maintained through selected Dodge Dealers







VEHICLE SPECIFICATIONS

Maximum speed	60 mph
Range* on a single charge in urban driving	Approximately 50 miles (standard model) 25 miles (basic model)
Examples of range attainable in urban driving in an 8 hour day	100 miles with 100 Amp. off-board charger with standard model 75 miles with 30 Amp. on board charger with standard model 50 miles with 30 Amp. on board charger with basic model
Maximum acceleration in basic model (25 mile range)	0 – 30 mph in 10 seconds
Maximum payload	From 760 lbs. to 2500 lbs. including driver depending on vehicle choice and battery configuration
Motor	Electric
Controls	Solid state electronics
Energy source	150-volt battery
Charging system	On-board charger operating from 230 V 30 amp outlet
Propulsion system	Linear Alpha, Inc.
Vehicles	Dodge Tradesman, Sportsman, Royal Sportsman, Maxivan, Kary Van, and Pick-up Trucks

PARTIAL LIST OF OPTIONS

Nearly all Dodge options can be provided

Off board charger,	230 Volt,	3 phase,	100 Amp.
	230 Volt,	1 phase,	50 Amp.

Gasoline heater, 20,000 BTU

*There is a trade-off between range and payload carried

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LINEAR ALPHA

ELECTRIC

THE 1975 LINEARVAN

Mr. McCormack. I want to observe at this point that if there is anyone present at this hearing who would like to submit material for the record, if you have not been invited to do so, or if you have not done so for any reason, not knowing that you could, I want you to understand that we welcome your statements. We will not have time to hear them in open hearings, but we will be happy to receive them and include them in the record.

I also want to point out the suggestion has been made, and we will be considering it, that we may want to recommend to the Bicentennial Commission that rental electric vehicles be provided by ERDA or DOT for use in transportation of tourists in Washington, D.C. next year, as one more method of demonstrating the feasibility of using electric vehicles.

I want to also comment that Congressman Ottinger mentioned the concept of steam vehicles and hybrid vehicles, and we very much agree with this. As a matter of fact, although we were not as explicit in writing the original bill, we did include in the definitions a provision that would allow us to involve any sort of a hybrid vehicle.

So I think we should start off understanding that we are including those, as Congressman Ottinger has suggested.

At this time it gives me great pleasure to welcome my colleague, Congressman Claude Pepper, here among us. Congressman Pepper has been an avid supporter of a number of our projects, including the solar energy and geothermal energy bills and energy conservation programs.

Today he is here with Dr. Vernon Roan of the University of Florida.

Also, a witness who will provide testimony later on, is my friend, Dr. Jim Kane, Deputy Assistant Administrator for Conservation of the Energy Research and Development Administration.

Claude, I want to welcome you here today, and ask you to please proceed with your statement as you wish.

STATEMENT OF HON. CLAUDE PEPPER, MEMBER OF CONGRESS FROM FLORIDA; ACCOMPANIED BY DR. VERNON ROAN, PROFESSOR OF MECHANICAL ENGINEERING, UNIVERSITY OF FLORIDA, GAINESVILLE

Mr. Pepper. Thank you very much, Mr. Chairman, and members of the committee.

I am very pleased to be here today as a cosponsor of the bill upon which you are holding this important hearing, and of another bill of similar character.

I ask your unanimous consent, Mr. Chairman, that I may offer my statement in writing for the record.

Mr. McCormack. With no objection, it will be so included.

[The complete prepared statement of Congressman Pepper is as follows:]

Statement of Hon. Claude Pepper

Mr. Chairman and members of the subcommittee, I am pleased to testify as a cosponsor of the bill, H.R. 5470, identical to the bill H.R. 6031, which I sponsored with my colleague Mike McCormack, being considered by this Subcommittee. The present energy situation makes it necessary that some measures be taken to conserve the limited fuel supplies that we have.

Americans have become very dependent on their cars, and this in turn has led to a greater and greater dependence on oil, much of which has to be imported to meet these needs. We are aware that the potential shortage of gasoline for our cars will last indefinitely, and that gasoline will become more expensive than it is today. These higher prices for gasoline will encourage many people to buy smaller cars, and this should decrease the demand for heavy, high-horsepowered, gasoline-consuming cars.

But what about other ways of looking at this problem? Is there an alternative? One alternative source of energy for powering our vehicles, cars as well as other vehicles, is electricity.

The idea of using electricity as a power source in our cars is not new because electric cars have been around, off and on, since the 1860's. However, when the internal combustion engine arrived on the scene, this engine went through such rapid improvements that the electric car practically disappeared by the late 1920's. Now when we are forced to look again at the electric car and consider our current predicament, we realize that the electric vehicle has the potential for being an alternative to the internal combustion engine-powered car.

While the electric vehicle may be a viable alternative to the internal combustion engine, the need for research is great. The legislation that I am cosponsoring addresses itself to many aspects of that needed research on electric vehicles.

As just one example related to research, consider the battery problem. The electric vehicle needs a battery that (1) is inexpensive, (2) delivers a high level of power for short periods of time for very little battery weight, and (3) has a large amount of energy in a lightweight package to provide a continuous supply of power that will permit the vehicle to travel a reasonable distance without recharging. However, we do not have a battery system that will meet these conditions.

This legislation will authorize in the Energy Research and Development Administration a Federal program of research and development, and demonstration designed to promote electric vehicle technologies and to demonstrate the commercial feasibility of electric vehicles. One area of research and development is specifically concerned with energy storage technology, including batteries and their potential for convenient recharging.

Other areas of research and development include the following:

1. Vehicle control systems and overall design for energy conservation, including the use of regenerative braking.
2. Urban design and traffic management for optimum transportation-related energy use and minimum transportation-related degradation of the environment; and
3. Vehicle design for maximum practical lifetime, ease of repair, and interchange-ability and replaceability of parts.

This legislation is not limited to the research and development aspects of electric vehicles, but it meets another vital need in that it provides for the demonstration of the commercial feasibility of electric vehicles by contracting for the practical manufacture of electric vehicles and by developing arrangements with other agencies and nongovernmental entities for the operation of such vehicles. We are aware that there are only a small number of projects being carried out on electric vehicles, so more government support is needed if electric vehicles are to become a part of our transportation system.

There is limited government support for electric vehicle use in the U.S. Postal Service, which tested electrically-powered trucks for mail delivery. The electric van is quite suitable for short, stop-go, low-speed trips made by a mailman in delivering mail.

Other projects have been undertaken in which electric vehicles have been developed for possible use in transportation systems. For example, the University of Florida has an electric bus project funded by the Florida State Department of Transportation. The University of Florida has been carrying out research on a hybrid electric bus that has its own recharging capability. The University of Florida would like to carry out additional research to determine the capabilities of this bus and has submitted a proposal for additional funds for this work to the Department of Transportation. Dr. Vernon P. Roan, Professor, Department of Mechanical Engineering, University of Florida, who is present today and has spearheaded this project will follow my testimony and give us the benefit of his expertise on this subject.

Another application that relates to electric vehicles includes the work being done by the Transportation Systems Center in Cambridge, Mass., in which comparative studies are being made on small buses powered by electricity, diesel, or gasoline engines.

Another project involves the Department of Transportation's Capitol Associates Program which subsidizes the purchase of equipment, i.e., in California there is a program in which purchase of electric buses was subsidized. These are a few of the projects that are underway in which electric vehicles are used.

In the area of electric cars for personal use, we can point to the progress that has been made by Sebring-Vanguard, Inc. of Sebring, Florida, which I understand Mr. Robert G. Beaumont, President of Sebring-Vanguard, Inc. will testify about on Thursday. This company has started producing and selling the "CITICAR", a lightweight electric car powered by a pack of batteries under the front seat. The car comes with a built-in charger and only has to be plugged into an ordinary electric outlet to keep the car running. A full charge can be accomplished overnight and gives the car a range of about 50 miles.

These are only a few of the applications involving electric vehicles, but this legislation will encourage much more to be done.

Moving beyond the research and development and demonstration areas, the legislation goes even further by arranging for the substitution of electric vehicles into the fleets of various Federal agencies, such as the U.S. Postal Service, the General Services Administration and the Department of Defense.

In addition, the legislation provides incentives for consumers and industry to adopt and utilize electric vehicles whenever the use of these vehicles would be beneficial.

Finally, the legislation provides that small business concerns and qualified individuals will have healistic and adequate opportunities to participate in the program to the maximum extent possible.

I strongly urge the Subcommittee to consider favorably this bill which will help make some progress toward solving the energy problem by using an alternative to our gasoline-powered vehicles.

Mr. PEPPER. And I would like to make a very brief statement before introducing my distinguished fellow Floridian, Dr. Roan.

In the first place, I want to compliment this committee for the fact that you have consistently taken an affirmative, a positive, approach to this energy question.

I do not say it in any unfriendly attitude of criticism, but too much of the program of the administration, and even of the Congress, has been of a negative character, it seems to me. Too often about all that has been proposed is that we raise the price of gasoline sufficiently so that it will be consumed in less quantity, presumably by the people least able to pay. I am not so sure that that is the best way of approaching this problem. We have immeasurable coal resources in this country, and yet we have not really yet done anything effective about maximizing the production, transportation, and conversion of coal into gas and gasoline.

I have a bill, H.R. 12121, a revision of a bill I introduced about 2 years ago, to set up a wartime authority, and substitute to that, which I hope may receive some favorable consideration.

But what you are doing today is not talking about people using their vehicles less. You are talking about an alternative source of energy, using the battery, using electricity, as a way of propelling vehicles.

So today I'm very proud to present a gentleman who has done some innovative engineering, pioneer engineering, in this area, Dr. Vernon Roan of the University of Florida, which is within the jurisdiction of my distinguished colleague and one of your distinguished Members here, Mr. Fuqua. Residing in his district, at the University of Florida, Dr. Roan has his bachelor's and master's degrees in engineering from the University of Florida; and his Ph. D. in engineering from the University of Illinois. He has developed a sort of a hybrid bus, which is suitable for carrying, say, 21 passengers, and has batteries that will operate the bus some 5 or 6 hours, and an auxiliary motor which is propelled by diesel fuel to be used in conjunction with it.

Dr. Roan has some slides here to exhibit to your distinguished committee, and I would like to save as much time as possible for him to make his statement and be available for questions.

Mr. Chairman, Dr. Roan.

Mr. McCormack. Thank you, Mr. Pepper. We very much appreciate your comments.

Dr. Roan, if you would like to insert your statement in the record, you may then proceed in whatever manner you wish.

Dr. Roan. Yes, sir. I would.

Mr. McCormack. There being no objection, your statement will be inserted in the record at this point, and you may proceed as you like.

[The complete prepared statement of Dr. Roan is as follows:]

STATEMENT OF VERNON P. ROAN, PROFESSOR OF MECHANICAL ENGINEERING, UNIVERSITY OF FLORIDA

In my opinion the Electric Vehicle Research, Development, and Demonstration Act of 1975 (H.R. 5470) is a good bill which should help provide a step increase in our capability to optimize and mass produce certain types of limited use electric vehicles such as urban people movers, small vans, and small buses. The potential conservation of petroleum-based fuels, reduction of urban air pollution concentrations, and decrease in urban noise levels appears to be quite significant even using present technology. There are, however, several modifications which I believe would strengthen the bill.

Suggested modifications to the bill include:

(1) More definitive instructions for establishing a minimum performance envelope for various classes of vehicles.

(2) A requirement for a more consistent and accurate means of establishing vehicle range.

(3) A means by which the true energy consumption of various vehicles may be accurately measured and compared.

(4) The addition of the hybrid-electric vehicle in the research and development activities.

I believe that, in general, the members of the Electric Vehicle industry are to be commended for the strides that they have made in recent years toward the development of a series of practical electric vehicles—especially since it seems that most of the progress has been made without the usual incentives from the Federal Government in the form of grants, research contracts and subsidies, which have been common in areas of rapid technological advancement. The lack of federal support in the research and development associated with electric vehicles has not been too surprising, since the original stimuli for the development of these vehicles, possible reduction in urban noise and air pollution, wasn't as convincing as the necessity of cleaning up the exhaust of the nearly ten million new I.C. engine vehicles being produced each year. It was also unclear whether there was public acceptance of limited performance vehicles.

The argument for reduced emission through the use of electric vehicles was somewhat controversial. Depending on the type and degree of emission control of the power plant from which the recharging electricity was being obtained, and the degree of emission control on the internal combustion engine used for comparison, the electric vehicle could actually cause more pollution than the conventional I.C. engine vehicle. Of course, the argument of concentrating the pollution in one area away from the urban center where it could be controlled was valid, as was the argument that if the power were obtained from a nuclear or hydro-electric plant, there would be little, if any, increase in atmospheric pollution.

The argument of a reduction in noise pollution had substance, but the noise pollution was considered a problem primarily in highly concentrated urban areas, and provided inadequate justification for an entirely new industry.

The current theme is that the electric vehicle will provide a substantial reduction in energy consumption. It is not completely clear that this theme is correct unless one is willing to compare an I.C. engine vehicle of one range and/or performance capability with an electric vehicle with completely different capabilities, since any vehicle designed specifically for urban use with reduced requirements in the way of payload, performance capability, and range, should provide a net savings in energy. However, even if the net energy savings of the electric vehicle are not dramatic, the savings in petroleum-based energy can be very significant. Clearly, in areas where the electric energy is produced primarily from coal, water power or nuclear sources an increasing savings in petroleum will result as electric vehicles assume a larger share of the transportation requirements.

While the electric vehicle industry has made great strides, I believe that there are some additional guidelines which should be established, perhaps in connection with the proposed bill, which will provide a better basis of comparison among the various researchers and manufacturers, and provide the public with a better understanding of the utility of these vehicles. First, I would recommend that there be established a minimum performance envelope. The purpose of this performance envelope would be to insure a minimum acceleration rate at different speeds, and to establish a minimum-top speed to be reached within a certain period of time. This envelope would help provide a reasonable level of traffic safety by minimizing obstructions when electric vehicles merge with conventional I.C. engine vehicles in urban or suburban traffic. A study should be conducted to determine exactly what this envelope should be, and it is likely that there should be more than one envelope representing different classes of vehicles. But typically, for an urban people mover, something on the order of 3 mph/sec. acceleration up to 20 mph and 30 sec. maximum to reach a top speed of 45 mph would seem reasonable. Furthermore, since the vehicle can operate for only a very short distance with a full or near full battery charge, the performance envelope should be met at, no more than say, a 50% battery charge. This is not to imply that all vehicles manufactured should meet such a performance envelope, but if they don't meet it, they should be recognized as special-purpose vehicles which would not normally merge with certain traffic patterns, and they should not be compared with vehicles which do meet the minimum performance envelope.

The next point is that criteria should be established to clarify the meaning of the frequently used but infrequently understood term, "range". Range obviously should denote the distance that a vehicle is capable of traveling. But under what conditions? Is it at a constant 5 mph? Is it at a constant cruising speed? Is it through urban traffic? It is clear that the variations in the so-called "range" are enormous, depending on the choice of the driving conditions during which the range is established. So a "standard" driving cycle is needed. Since the primary utilization of the electric vehicle is likely for urban driving, then a standardized driving cycle should reflect urban conditions. My suggestion would be to generate a version of the urban driving cycle used for the EPA emissions test, modified for lower acceleration rates and reduced top speeds, and range then would be determined by the total distance that the vehicle could travel while conforming to this (or some other) driving cycle. On this basis it would be quite reasonable to compare the range of various vehicles or of the same vehicles with different battery packs, or whatever, on a consistent basis. I might further add, I don't believe it is reasonable to call the range the total distance covered when the vehicle will no longer continue to move, but rather when the vehicle will no longer meet some minimum acceleration and/or top speed values, perhaps an initial acceleration of 1.5 mph/sec. and a top speed of say 20 mph. Finally, since range and performance are both determined partially by the battery temperature, then these values should be established for a given temperature, say 59° F.

Since the primary purpose of the proposed bill is to expedite the development of feasible electric vehicles which will conserve energy, a means should be established for consistently and accurately determining the energy consumed by the vehicle. Specifically, when the energy requirement for a particular vehicle is reduced to a form, such as a certain number of miles per kilowatt-hour at a given speed, it is extremely important that this energy consumption be qualified. What is meant by this is, that even though the discharge of energy from the storage batteries through the drive system may be measured and may be representative of the figure quoted, it is not the energy that is of primary concern to the public. Their concern, and yours, is how much energy must be delivered from the electrical generating plant to provide the driving energy for the vehicle. Further, the amount of energy required to charge or partially charge a given storage battery depends on many variables. The most important of these are the state of charge of the battery, and the rate at which the battery is being recharged. Therefore, when the energy consumption is specified, say for covering a particular distance while conforming to a particular driving cycle, it should be specified through the amount of energy required to recharge the battery over a given period of time. Eight hours might be a reasonable time period, since to mesh with the non-peak requirements of the power company the time period from 11 or 12:00 in the evening to 7 or 8:00 in the morning would be the most advantageous.

Another possibility that should be considered in this bill is some thought for the development of other than the pure electric vehicle. For a given type of storage battery, motor and control system, the range of a pure electric vehicle for a specified type of driving cycle is going to be determined primarily by the fraction of the total vehicle weight that is made up of the weight of the storage battery. This means than an electric vehicle using lead acid storage batteries will necessarily have a relatively large percentage of its weight in the form of storage batteries if it is to have a reasonable range. One alternative is the hybrid electric drive system. "Hybrid electric drive system" refers to a system which is similar to that in an electric vehicle but also contains a small heat engine and generator. The hybrid may utilize almost any type of heat engine including steam, gas turbine, diesel, etc. The drive system may be of the series or parallel type using any of several types of control systems. In any case, the hybrid has both advantages and disadvantages and its usefulness would depend on the particular circumstances. The disadvantages include additional cost and complexity due to the redundancy of power sources, and the likelihood that petroleum-based fuel would be used when the engine was operating (although an external combustion engine using dry fuels is possible). The advantages include the fact that the battery size can be greatly reduced as compared to the all-electric vehicle and the engine size can be greatly reduced as compared to a purely I.C. vehicle. Further, it is not necessary to operate the engine for the majority of short trips and the battery may be recharged at night using household electrical current. The heat engine-generator will provide the additional range or performance when needed. Also, if the heat engine were an Otto cycle (gasoline) or diesel, both exhaust emissions and fuel consumption are minimized by operating the engine at near constant speed and load, as compared to a conventional I.C. engine automobile.

The Mechanical Engineering Department at the University of Florida has developed four electric driven vehicles: a pure electric compact car, a pure electric mini-van, a hybrid-electric urban car, and a hybrid-electric small bus. All were developed from previously existing vehicles, although one retained little more than some sheet metal from the original configuration. Controllers used have included several contacter types, power transistor version, and two SCR chopper units. We have tried using no transmission, transmission without clutch, and transmission with clutch. Finally, both shunt and series motor and several types of batteries have been used.

We have concluded that both the pure electric and the hybrid electric are feasible for limited use applications. It is also clear that new components are generally needed rather than adapting hardware designed for the internal combustion engine vehicle. Lastly, while the lead-acid battery can be successfully utilized, new batteries with higher power densities and energy densities are needed to provide better performance, range, and payloads while retaining relatively small vehicle size.

Dr. Roan. Thank you.

Mr. Chairman, I do appreciate the opportunity to be here before this committee

Actually, my main comments on the bill concern the omission of some funds toward the development of the hybrid electric vehicle, and Mr. Ottinger has already made comments to the effect, as have you, that this will be included.

I did have a few additional suggestions, which I might summarize from my written statement here.

We have found, in reviewing the literature, that we have a great deal of difficulty trying to make comparisons among various electric vehicles. Specifically the performance, the range and the energy consumption are all very much interrelated, and I would suggest that in the formulation of this bill it might be worthwhile to try to define more precisely some means by which comparisons can be made in these very important areas.

1. Specifically, more definitive instructions for establishing a minimum performance criteria for various classes of vehicles.

I realize that you have included in the bill at this point instructions for reporting in 180 days a suggested performance. However, I think that it might be worthwhile to try to make this more specific, and I'll demonstrate that in a moment.

2. The requirement for a more consistent and accurate means of establishing vehicle range.

Very few people know what's meant by range, because the range is so heavily dependent upon the type of driving that the vehicle is subjected to. So you can't compare a vehicle with a 20-mile range and a vehicle with a 50-mile range, unless you're also comparing them on the same type of driving cycle.

3. A means by which the true energy consumption of various vehicles may be accurately measured and compared.

The purpose here, the thing that we're really interested in, is how much electricity we have to provide from our power generating stations in order to recharge the batteries to the point where the vehicle can be used. The amount of power that's indicated, say, through the voltmeter and ammeter on the vehicle that's being used, isn't necessarily indicative of the amount of energy that we have to supply to the vehicle to keep it mobile.

4. And, finally, as I've already stated, I do believe that the addition of the hydbrid electric vehicle in the research and development activities would be important. The hybrid electric does offer some very distinct advantages under some circumstances, and so I think that it's worth further investigation.

The slides I've prepared relate mostly to the hybrid electric vehicle. We have developed two of these at the University of Florida. One is a two-passenger urban car. The other is a small bus that's capable of carrying 21 passengers. Both of these are currently operational. We are driving them. We're trying to collect data, although at the present we are trying to get additional funds for further evaluation.

I do have on the slides some curves. But I will try to keep them as brief as possible.

[Slides shown.]

The first curve shows the power requirements for a typical vehicle—this is in the 3,000-pound weight category—as a function of the speed. The power indicated is to maintain a constant speed on a straight, level road.

You'll notice that at a speed of, say, 45 miles per hour only about 10 horsepower is required for this 3,000-pound vehicle. The remainder of the horsepower available is for acceleration purposes and for the top speed, whatever the top speed is desired to be.

By the way, I've also included on this curve our own experimental vehicle. It's weight is just slightly under 3,000 pounds, without passengers. And, as you'll notice, our power requirements are slightly higher than we would normally take for a typical internal combustion vehicle. We don't know exactly why yet. We're trying to isolate these things. But it does seem as though it's associated with the electric motor drag.

This curve, the upper curve, shows the amount of power you would normally have available from a gasoline engine in your automobile. The vertical distance between the lower curve and the upper curve is the excess power that you have available for accelerating your vehicle. Ordinarily, in your IC engine car the power available is due to the size of the gasoline engine. In the hybrid electric vehicle we have the additional power requirements available from the storage batteries; the engine would be only that size required to supply the average power.

I might briefly mention the two basic configurations of the hybrid electric vehicle; the series configurations and the parallel configuration.

In the series configurations the vehicle is basically an electric vehicle. The rear wheels are driven only by an electric motor. The power for driving the vehicle then comes through the electric motor to the rear wheels.

In the parallel configuration there is a gearing mode, where the heat engine can drive the rear wheels directly, as Mr. Ottinger has pointed out, after, say, you have reached some predetermined speed.

[Next slide shown.]

Our particular vehicle is like this: We do have a series configuration. Ours is basically an electric vehicle that simply carries a small engine and generator onboard. The hybrid vehicle doesn't necessarily have to have the engine generator operating while you're driving it, but you may operate it. The ideal situation would be to use it as an electric vehicle for the numerous short trips, and where there was a requirement for a longer trip, or for temporary higher speed, you could have the engine running.

[Next slide shown.]

One last mention on the advantages of the hybrid. If you do have a smaller engine operating near the rated continuous horsepower, the emissions are minimized. As you will notice on this curve here, as the load goes up, that is, if this engine were, say, a 10-horsepower engine, if your requirement is up around 6 to 8 horsepower, the emission of carbon monoxide is minimized. The unburned hydrocarbons are very nearly a minimum also, with a slight increase in the oxides of nitrogen.

So operating the gasoline engine, or the diesel engine, at a relatively constant speed and load near its rated horsepower is the best way to minimize the uncontrolled emissions from the engine. The same is true for the fuel consumption. The minimum specific fuel consumption occurs at somewhere around three-fourths of the rated continuous horsepower of the engine, and with your hybrid vehicle you have an engine operating near its maximum power output.

[Next slide shown.]

These are specifications for the small two-passenger car. The weight is 2,980 pounds. For this car, by the way, the range is limited only by the amount of fuel in the tank. If you wish to take it as far as possible in a pure electric mode, it has a range of 10 to 15 miles, depending on the kind of driving that you subject it to.

[Next slide shown.]

This is a photograph of the car. As I say, it is operational. We have been conducting various experiments on it for 3 years now. We've used different kinds of batteries, control systems, electric motors, tires, and so on, in an effort to determine what really is the best configuration for the hybrid.

[Next slide shown.]

In the engine compartment is a small engine generator. This, by the way, is a 14 horsepower, which is considerably less than you would normally expect in a 3,000 pound vehicle.

[Next slide shown.]

The size of the vehicle is also important. If you're going to have it driven electrically, you'd like it as small as possible.

The rear bumpers of those cars [indicating on slide] are lined up, by the way.

[Next slide shown.]

The bus we developed from an existing bus, the Electro-Bus, which was originally all electric. We did convert it to a hybrid electric.

[Next slide shown.]

We have two batteries, one on each side of the bus, 42 volts each, a little over 600 amp-hour capacity.

[Next slide shown.]

Where the battery was originally located in the bus, we put in a small diesel engine, a three-phase alternator, and the various support equipment.

[Next slide shown.]

We have put together a computer simulation, and I just wanted to show you a few results. I'm trying to demonstrate the importance of specifying the kind of driving cycle that you're talking about. In this case we chose a particular driving cycle. This particular driving cycle had six stops per mile, and we used this curve to determine the output that our generator would have to have for the vehicle to be able to operate continuously. As you can see, in this particular case it would take about a 30-kilowatt generator, which is approximately what we have in our bus. If it was in a pure electric mode, there would be, for this particular driving cycle, about 1½ hours of continuous driving available. This is a rather severe cycle, and with a less severe cycle it would go longer and farther in the pure electric mode.

[Next slide shown.]

This shows the importance of the cycle. Cycle 1, cycle 2, and cycle 3 are similar. Cycle 3 is the most severe. It has a higher top speed requirement, and it has more stops per mile. With a 30-kilowatt generator we would not be able to keep up with the electrical requirements in this particular case.

[Next slide shown.]

The miles per gallon that we can achieve is also a very misleading thing. This is miles per gallon of diesel fuel, and you will notice the figures are quite high. But, as I say, it's misleading because of the fact that we're talking about a constant speed. In stop-and-go city driving traffic, with six stops per mile, this is actually about 7 miles per gallon. So we're talking about a factor of 2 on energy consumption, depending upon the kind of driving mode that you specify.

[Next slide shown.]

Finally, I have suggested in my written statement that minimum performance envelopes be established. One for an urban car might be the kind that I have shown in the lower curve here. This would provide a speed of 45 miles per hour after about 30 seconds and your initial acceleration rate would be somewhere in the order of 3 miles per hour per second.

If you compare that with the performance of an ordinary 40-horsepower Volkswagen, you can see it's substantially lower.

However, this kind of performance, I think, would be acceptable. But, there has to be a level at which the performance is not acceptable, from a safety standpoint if nothing else.

That's all of the slides I have.

Mr. McCORMACK. Thank you, Dr. Roan.

Do you have any other statements you would like to make?

Dr. ROAN. No; that's all at this time.

Mr. McCORMACK. Thank you for your statement.

I am sure we all very much agree with you that we need a definition of performance criteria, just as, by the same token, we would not want to put it in the bill itself. We want to provide that ERDA would do this, assuming that they would have the professional competence to do this. I think we agree on the goal. The reason we do not put it in the bill is that we do not feel competent to do so. We feel it would be a product of a great deal of research, which we cannot do but which ERDA can. I am sure you understand that.

Dr. ROAN. Yes, sir, I do. My comment really was not that you should put it in the bill, but rather perhaps be a little more definitive in your instructions for establishing the envelope, or envelopes, as the case may be.

Mr. McCORMACK. Mr. Brown, do you have any questions?

Mr. BROWN. No, thank you, Mr. Chairman.

Mr. McCORMACK. Mr. Ottinger?

Mr. OTTINGER. No questions. Thank you.

Mr. McCORMACK. Mr. Harkin?

Mr. HARKIN. No, thank you.

Mr. McCORMACK. Mrs. Lloyd?

Mrs. LLOYD. No questions. Thank you, Mr. Chairman.

Mr. McCORMACK. Mr. Fuqua?

Mr. FUQUA. No, thank you.

Mr. McCORMACK. Mr. Thornton?

Mr. THORNTON. No, thank you.

Mr. McCORMACK. Mr. Goldwater?

Mr. GOLDWATER. No questions.

Mr. McCORMACK. Mr. Hechler?

Mr. HECHLER. I am just interested in a general way whether you've observed any inhibiting pressure from the existing industry against the development of these vehicles.

Dr. ROAN. No, sir, none that I am aware of.

Mr. HECHLER. Thank you.

Mr. MCCORMACK. Dr. Roan, I want to thank you very much for coming today. We very much appreciate your testimony.

Congressman Pepper, we very much appreciate your coming today and leading off.

Mr. PEPPER. Thank you, I am delighted to be here.

Mr. MCCORMACK. Thank you very much.

[Answers to additional questions referred to Dr. Roan follow:]

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DEPARTMENT OF MECHANICAL ENGINEERING

JUL 28

July 25, 1975

The Honorable Mike McCormack
Chairman, Subcommittee on Energy Research
Development and Demonstration
U. S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Representative McCormack:

Thank you for your letter of July 10, 1975, inviting me to respond to additional questions relating to electric vehicles and HR 5470. I realize that the issues and question sheets were made up for all of the participants in the discussion, thus covering areas that would be outside of the scope of interest of any one individual. I will therefore respond to questions which I feel are generally within my scope of knowledge relating to this subject.

Since I am omitting many of the questions, my responses below are listed according to the question number on your survey sheet.

Question 2-f: In my opinion, it will be necessary to change several of the safety regulations to enable a variety of companies to participate in the electric vehicle program. It is vital that the body and chassis of the electric vehicle be as light and efficient as possible, and the electric vehicle would not generally be expected to encounter the severe type of high-speed crash that a conventional IC engine automobile might. Therefore, some regulations should be eliminated or modified. Further, since the current bumper law is questionable at best, it should be eliminated (although a standard bumper height should be required). Passenger restraint, while certainly a necessary item, should be no more severe than is actually necessary for the scope of operation of the vehicle. (I might add that I feel that it will also be necessary to add regulations to ensure a reasonable capability of the electric vehicle to merge with other types of traffic).

Question 3-a: The various answers to this question have been offered so many times that it isn't necessary to repeat them. One comment though -- it seems as though the major implication of the centralization of energy production is the fact that it would be immensely easier to switch the type of energy being used as the primary source. The near-term electrical energy source is going to be primarily coal or nuclear, but in the future it is possible that hydrogen or some synthetic fuel may be more desirable.

Question 3-b: In my opinion, even with transportation electrification, the short term alternative is going to be less individual transportation and more mass transportation; and the long term alternative is going to be even less individual transportation, and possibly less mass transportation. Without the electrification of transportation systems, it seems inevitable that in the very near future, drastic measures will have to be taken to reduce the consumption of petroleum-based energy. Either the combination of taxation and price increase will be so overwhelming so as to reduce private transportation to the barest essential; or, some type of rationing program by the government will reduce transportation to a minimum, or a great deal of chaos will ensue. In short, in my opinion, we have no reasonable alternative other than to pursue as vigorously as possible the initiation of both local and long range transportation systems which do not require petroleum-based fuel.

Question 4: The short range prospects for the electric vehicle control technology appear to be primary dependence on the SCR chopper type controller. The technology, however, is already quite acceptable, and probably when the controllers are designed specifically for passenger car use they will become even more effective at a reduced price. The long range alternative would seem to be a power transistor type controller, which is inherently more simple and lighter, and should be less expensive when the technology is more completely developed.

Question 5: The provision of maintenance facilities for electric vehicles will not likely be a major problem except possibly in the very initial stages of the program. The reason for this is that most of the technology -- the basic running gear of the vehicle -- is well within the grasp of current mechanics and electricians. The control systems are relatively trouble-free and I would expect the major manufacturers to provide factory rebuild service for the customers.

Question 6: There will be an effect on total energy usage due to the adoption of the electric vehicle. In my opinion, this effect is going to be very positive. While the overall conversion from thermal energy to propulsion energy of the electric vehicle is not significantly better than that in the current IC engine vehicles, the fact is that people will readily accept a much lower level of performance from an electric vehicle. The lower performance means less power required at the rear wheels, and this means less total consumption of energy for the typical driving. Furthermore, it seems probable that an appreciable overall efficiency increase of the electric generating plants will be realized due to the utilization of their capabilities more fully during the off-peak hours. It is unlikely that there will be adequate generating capacity for a major shift to electric vehicles unless a recharging of the vehicles is permitted only within certain hours. Many of the nation's largest generating stations could not tolerate the additional load during peak usage hours by an appreciable number of electric vehicles charging their batteries at relatively high currents.

Question 7: Synthetic hydrocarbons and alcohol will probably have little effect on the electric vehicle program. The reason is that an enormous capital outlay will be required to produce either of these fuels in large quantities. Further, the production costs, thus the unit fuel costs, will surely be high compared to a basic fuel, such as coal, which will be generating electrical power. Synthetic gases such as the light hydrocarbons and hydrogen will have little, if any, effect. The effect of hydrogen will be positive if it is ever produced in large quantities since hydrogen is not currently a very portable fuel and is not likely to be so in the near future. Therefore, if it were produced in large quantities, it would be used as a non-polluting fuel in electrical generating stations or stationary power plants.

The hybrid systems will represent ultimately a different class of vehicles. I see the pure electric car, at least using current battery technology, as a short range, low performance vehicle. On the other hand, a comprehensive development program on hybrids could produce a higher performance and longer range vehicle, which would have more diverse applications.

Question 8: Heating and air conditioning both need to be considered very seriously. The heating is a much less severe problem, in that small quantities of petroleum-based or synthetic fuels can be used to provide all of the heat necessary to warm a car and defrost the windshield, etc. The only mechanical energy required in a heating system is for a small low-powered electric blower to circulate the warmed air through the vehicle or across the glass area. Air conditioning is a feature that, while not required, will certainly make the electric car more palatable to the general public. Almost by definition, the electric car is going to be moving slowly in urban traffic areas, which represent the worst conditions from the standpoint of passenger comfort. Unfortunately, there is no current technology available to provide the air conditioning without using an appreciable amount of energy driving compressors and blowers. The amount of energy is so great that it would detract materially from the performance capability of a typical electric vehicle. It seems though that appreciable advances can be made in this area through the use of more efficient refrigeration systems and better insulation of the vehicle.

Question 9: Special safety problems undoubtedly exist. In some ways the vehicle will be more safe than a conventional vehicle, and in some areas it will be more dangerous. The vehicles will invariably have a very low center of gravity, making them fairly stable, and they will not have the large acceleration and top speed capability which undoubtedly causes many accidents in conventional vehicles. From the standpoint of the single vehicle accident, they will likely be safer than the subcompact conventional vehicles. In multi-vehicle accidents they could potentially be more dangerous due to the size, the possible electrical shock hazard, and of course, the possible spillage of acid. These latter hazards could be minimized through a minimal amount of innovation, such as using failsafe disconnect systems to reduce shock hazards, and lining the battery compartments with some flexible acid-resistant material. At the very least, the safety requirements should be reviewed and relaxed wherever possible, when it would mean an appreciable saving in weight. As I've already mentioned, I don't believe the 5 mph bumper should apply to electric vehicles.

Question 10: The energy storage problem is undoubtedly the most severe restriction on electric vehicles. The development of a better battery, or for that matter, any other means of storing larger quantities of energy, would give impetus to electric vehicles. Since this is an area of prime importance, as much attention as possible should be given to it. I don't think the current effort is great enough, and I'm not at all sure that the battery companies should be the ones to carry the brunt of the research load. This seems an ideal area to utilize the talents in the various universities through research programs and government agencies such as NASA with their enormous technical capability. The same comments regarding effort apply to work on the intermittent and load leveling problems. Whether or not the utilities will be overtaxed for a major shift to electric vehicles will depend almost entirely on the ability to truly accomplish load leveling.

Question 11: It is clear that some type of mass transit is in fact the answer. The energy efficiency of most mass transit systems is like ten times as great as a conventional automobile. In the short term, the petroleum-based mass transit such as trains and buses will have to provide the capability. In the long range, as much as possible of the long range transportation load should be shifted to electric vehicles. Electrified roadways might prove beneficial for using dual mode vehicles in certain circumstances, but the cost of initiating such a program, plus the energy loss associated with it and all the hazards, would almost surely eliminate it from large scale applications.

The question of electric mass transit systems being incorporated into the demonstration program is not really clear. We already have an appreciable number of electric mass transit systems -- electric trains, electric buses, subways, etc., that have been in use for many years. About the only area that has not been thoroughly investigated is the battery-powered mass transit vehicle. While there are a few of these in operation now, it might be advantageous to provide some funding to further investigate the potential of this type system.

The possible role of the fuel cell depends on what happens to technology in this area. Currently, it seems most unlikely for small systems because of the relatively low power outputs and the relatively high cost per unit of electrical power. The efficiency of fuel cells is extremely good, however, compared to the fuel utilization of a conventional power plant. For some large scale applications, this might well override the cost and space required for the hardware, but not in the case of passenger automobiles.

Question 12: The total energy problem certainly should be considered in connection with this program. As I have pointed out, there seems to be little savings in overall energy if the same type of performance is expected from an electric vehicle as from a conventional IC engine vehicle. However, since this type of performance is not generally expected, and since the passenger carrying capability will be reduced, and random driving will also be reduced, then there should be an appreciable savings in overall energy consumption.

I don't feel personally that the impact of bicycles, either electric or non-electric, will be very great, even if carriers are made available on public transportation systems. My reasoning for this is that the majority of the urban trips are made by housewives and businessmen, neither of whom would be very inclined to use a bicycle for transportation. The local impact in some areas could be significant, such as in the vicinity of large high schools, colleges, universities, and other types of institutions where large numbers of people gather. The effect of this one passenger type commuter vehicle would probably be even less as it simply doesn't have enough flexibility to be attractive. Even though the average urban passenger load is only around 1.5 persons, the fact is that almost everyone who uses an automobile for urban use needs the capability for at least one more passenger.

Question 13: The fact that some foreign countries are ahead of us in the design of EV components seems to me to be almost irrelevant. Countries have been duplicating each other's advanced technologies ever since the beginning of technology, and it won't likely cease. So undoubtedly many of the concepts that are developed by one country will be utilized and even improved by other countries. It doesn't seem to me as though any action would be necessary at this time. If real technological breakthroughs are tied up through some kind of international law or patent situation, then some kind of action would probably be necessary to protect the United States' industry and the country's economy.

Question 14: I would list five basic objectives which hopefully could be attained through the technology demonstration programs.

1. To foster invention and innovation. The electric vehicle needs to be designed from the ground up. Tires, brakes, chassis, steering, differential -- all of the components have basically different requirements from the conventional ICE automobile, Further, there is much room for improvement in the design of the electric propulsion motors, the controllers, and of course, the all-important energy storage system. While it's unlikely that any one person or group will come up with the best answers in all of these areas, it does seem that with so many individuals working on, and thinking about, the problems, there will be rapid advances in the overall technology.

2. Locate and correct any weak links found in the electric vehicle concepts. For example, with an appreciable number of these vehicles in operation in all kinds of environments, the cold weather problems, the problems merging with traffic, problems of failure of various components, potential safety hazards, etc., will be investigated more thoroughly. Some of the results of the demonstration will undoubtedly change basic concepts regarding electric vehicle technology.

3. To establish public acceptance of relatively low performance electric vehicles. With an appreciable number of people driving the vehicles in communities all over the country, it is much more likely that the concepts will catch on than if left to natural evolution. And certainly public acceptance is going to be one of the main, if not the main, criterion in determining the success of the overall program.

4. To encourage the evolution of a viable new industry, I believe it is well established now that there is a place for the electric passenger vehicle. It seems certain that if conditions are right, in the near future a large market will develop both in the United States and in foreign countries. It would certainly behoove the United States to have developed a viable industry capable of supplying this demand rather than having dependence on foreign manufacturers.

5. Establish the true energy savings, if any, associated with electric vehicles. With the proposed number of vehicles in operation, the energy savings associated with a typical operation should become a fairly easy quantity to determine.

In my opinion, both the time schedule and the funding are appropriate as currently proposed. Having heard some of the witnesses, I would have to agree that the one-year and three-year time periods are very very short. On the other hand, the small-sized organizations who will be performing most of the tasks do not have the managerial inertia and reams of paperwork involved for simple tasks and can proceed much more rapidly than government agencies or large industrial concerns. Further, the current fuel situation is so extremely precarious that we do not have time to afford the luxury of a more extended, leisurely program. I personally believe that we have more to gain than to lose by keeping the time period as short as possible. With a proper distribution of funds and technical effort, I believe the proposed goals can for the most part be accomplished.

I do not believe the program should be delayed until advanced batteries are made available, as many companies have been working for years and haven't developed one yet. Perhaps the stimulus of a program such as this is exactly what is needed to make the advanced battery a reality. As far as the advantages and disadvantages of having the demonstration programs proceeding parallel to the battery development, I don't really see any reasonable alternative. Certainly, due to the relative weight of the battery and its effect on the overall vehicle performance, it would be most desirable to have the advanced battery to build the vehicle around. However, many of the problems can be solved and many components optimized independent of the availability of the battery.

The non-technological benefits of the demonstration program are lumped into the public awareness of the energy problem and awareness of the gains in energy savings that can be realized through other modes of transportation, and the acceptance of the lower performance urban vehicles. In my opinion, these goals can be realized to a large extent with the current lead-acid batteries.

Cost effectiveness is one area where the program is likely to suffer a bit. If one makes a few simplifying assumptions, a rough comparison of the cost effectiveness can be made. For example, if it is assumed that gasoline is utilized with an efficiency of 17%, the effective energy density of the gasoline is about 1,000 watt-hours per pound. As a comparison, a lead-acid battery energy density is approximately 10 watt-hours per pound. In other words, it would require approximately 100 times the weight of lead-acid batteries to provide the same amount of useful energy as compared to gasoline. Similarly, if one compares the power density of a typical gasoline engine versus the lead-acid battery, assuming approximately 4 pounds per HP for the gasoline engine, and 36 watts per pound for the best lead-acid battery, the equivalent power density comparison then is approximately 180 watt/lb for the gasoline engine versus about 36 for the lead-acid battery. In other words, it would take approximately 5 times the weight of lead-acid batteries to supply the instantaneous power comparable to a typical gasoline engine. In terms of operating cost, if one assumes a battery cycle life of 1,000 cycles for a lead-acid battery and the cost of $1.00/lb for electric vehicle-quality batteries, then the direct battery cost would be approximately 10¢/kwh of energy consumed. The cost of recharging must of course be added to this, and at a usable unit electricity cost of 5¢/kwh, this would make the total direct battery operating cost approximately 15¢/kwh. Further, assuming an energy requirement of approximately 1/2kwh/mile, the total direct battery energy cost would correspond to about 7-1/2¢/mile. In the way of comparison, the cost of gasoline would have to be $1.05/gallon for the same amount of usable energy. Therefore, it seems clear that the cost effectiveness of the electric vehicle cannot really compete favorably with the IC engine vehicle of the same performance until the price of gasoline passes $1.00/gallon.

Question 15: The hybrid vehicle really presents a different set of problems from the pure electric vehicle. As such, the analysis, as well as the basic vehicle design, would be quite different. It should be considered as a separate phase of this program, and should receive an appreciable amount of effort. The type of hybrid system that would benefit the most from the government-sponsored program would probably be the hybrid-electric. This is due to the fact that there would be, in conjunction with the rest of the program, a great deal of effort directed in the areas of electric motors, batteries, controllers, etc. The time frame for the hybrid should be somewhat longer than the all-electric vehicle, because it is more complex and requires considerably more analysis prior to actual hardware construction. The three-year period seems reasonable, but I don't think the hybrid should be included in the first demonstration phases at one or two years.

Question 16: I think that a rental or leasing component should definitely be included in the program. The cost should be such that a vehicle is within reach of any American citizen who can currently afford to operate a conventional gasoline-powered automobile, At the end of the program the vehicles could perhaps be sold to recoup some of the costs.

Question 17: The problem of mix from a safety standpoint can be very severe. There will undoubtedly be people trying to utilize these vehicles for freeway traffice, or up hills or mountains, or extremely cold weather where the battery efficiency is low, which will create dangerous situations. In my opinion, a minimum performance with acceleration rates somewhat lower than our poorest performing gasoline-powered vehicles and a top speed of at least 40-45 mph should be specified for the demonstration vehicles. I have explained my views in this area more fully in my testimony before the committee but I will be glad to supply further information if you so desire.

Question 18: In response to this question, I have made a few approximate calculations summarized below.

Estimates of Energy Waste and Power Plant Re-charging Capability

A. Energy Waste of Conventional IC Engine Automobiles Due to Idling at Stop Signs, Traffic Lights and Heavy Traffic.

Assumptions:

1. Two hours per day of urban driving per vehicle.
2. 13% to 20% of urban driving time spent idling (Ref. SAE Paper 730553).
3. Average fuel usage -- 1/2 gallon per hour for idle conditions.
4. 250 days per year of urban driving.
5. 0.5 kwh/mile energy required for electric vehicle.
6. Electric power plant efficiency of 35%.

Conclusions:

1. Gasoline waste is about 32 gallons per year per automobile. Nationwide, assuming 50% of automobiles for urban usage, the fuel waste is about 1.5 billion gallons, or about 36 million barrels.
2. This energy waste would represent an additional 350 kwh per automobile if the fuel was consumed at the power plant.
3. The "free" miles that could be traveled with this energy used in electric vehicles would be about 800 miles per year (for each electric vehicle).

B. Effect on Electric Power Plants of Re-charging Urban Electric Vehicle Batteries.

Assumptions

1. Energy required for electric urban vehicle is 0.5 kwh/mile.
2. Average driving 30 miles per day.
3. Average home electrical energy consumption in summer months is 1800 kwh/month.
4. Average home electrical energy consumption is 1000 kwh/month yearly.
5. Peak home electrical power requirements are about twice the average.
6. The average home electrical power requirement between 12:00 and 6:00 a.m. is one-fifth the daily average.
7. Some of the above values were based on local utility company (City of Gainesville) published figures.

Conclusions:

1. The average monthly electrical power requirements for recharging the electric vehicle batteries will be about 500 kwh/month.

2. For the six-hour assumed recharge period, the power required is about 2.5 kw per car.

3. The average normal daily power requirement per household is about 2.45 kw.

4. If all recharging was accomplished between 12:00 and 6:00 a.m., the average power plant output would be raised from about 20% of peak capability to about 75% of peak capacity. (Assuming each household has an electric vehicle.)

5. Virtually no recharging could be allowed during peak electrical usage hours without overloading the plants.

6. The average electrical power customer would increase his average electrical energy usage by about 50%.

I hope the above comments will be of some value to you. Please contact me at any time if I can be of further service.

Yours truly,

V. P. Roan
Professor of Mechanical Engineering

VPR:pr

cc: The Honorable Claude Pepper
The Honorable Don Fuqua

Mr. McCormack. Our next witness is Dr. James Kane, Deputy Assistant Administrator for Conservation, Energy Research and Development Administration.

Jim, we are glad to see you back again, and particularly since you're so wealthy now that we've provided all this money for fiscal 1976. We will be curious to know whether you can spend it or not.

STATEMENT OF DR. JAMES S. KANE, DEPUTY ASSISTANT ADMINISTRATOR FOR CONSERVATION, ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION; ACCOMPANIED BY DR. JACK VANDERRYN, ASSISTANT DIRECTOR FOR ENERGY STORAGE, ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION AND JOHN BROGAN, ACTING DIRECTOR, DIVISION OF TRANSPORTATION, ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

Dr. Kane. Thank you, Mr. Chairman, and members of the committee.

I have a written statement, Mr. Chairman. With your permission, I will read part, and amplify on part, and submit it for the record. Is that satisfactory?

Mr. McCormack. It is perfectly satisfactory if you would like to have it submitted for the record and speak from it, if you like.

Dr. Kane. Yes, please.

Mr. McCormack. We will insert it in the record, and any additional comments will go into the record.

Would you care to introduce your staff?

Dr. Kane. Yes, I will. On my left is Dr. Jack Vanderryn, who is Assistant Director for Energy Storage. On my right is Mr. John Brogan, who is Acting Director of the Division of Transportation, both within the Office of Conservation.

[The statement of Dr. Kane is as follows:]

Statement of Dr. James S. Kane, Deputy Assistant Administrator for Conservation, Energy Research and Development Administration

INTRODUCTION

Thank you, Mr. Chairman and members of the Committee for the opportunity to give testimony on H.R. 5470, "The Electric Vehicle Research, Development and Demonstration Act of 1975." My name is James Kane, and I am the Deputy Assistant Administrator for Conservation in the Energy Research and Development Administration (ERDA). I am accompanied today by Mr. John Brogan, Acting Director, Division of Transportation, and Dr. Jack Vanderryn, Assistant Director for Energy Storage, both within the Office of Conservation. The Division of Transportation is responsible for the ERDA programs to develop and demonstrate energy efficient and environmentally acceptable means of transportation. The Office of Energy Storage is responsible for programs to develop alternative methods of efficiently storing energy for application in both mobile and stationary systems.

In order to present my views on the proposed legislation in the proper context, it would be well first to provide the Committee with background information on related ERDA activities. I will concentrate on that part of our program devoted to developing new transportation systems which will be capable of being recharged using electricity. This will be followed by a presentation of our views on the proposed legislation.

FACTS CONCERNING CONSUMPTION AND SUPPLY PATTERNS

Our planning has been influenced by several facts relating to energy consumption and supply patterns. These are:

Transportation consumes about 25% of the total energy used in the U.S. annually,

Automobiles account for more than 50% of the total transportation sector energy consumption,

Transportation is presently almost completely dependent on petroleum as its energy source,

We are currently importing about 35% of the petroleum which we consume, and

All of the authoritative projections of the U.S. domestic supplies (including Alaska) of recoverable petroleum indicate that domestic production will drop to a small fraction of total demand sometime in the early part of the next century.

PROGRAM OBJECTIVE

Our work is cut out for us—we must not only reduce energy consumption while greatly increasing the efficiency with which we use energy in transportation, but we must also find ways to get the transportation sector off of its petroleum energy base. Accordingly, one objective of the ERDA transportation program is to develop and demonstrate the technologies necessary to markedly reduce transportation's dependence on petroleum.

PLANNING STRATEGY

Recognition of the above facts led to the formulation of a four-part strategy to meet this program objective. Our strategy aims at ensuring that in the future a number of options will be available to perform transportation functions regardless of the present uncertainties with respect to energy sources to be used. The four parts to the strategy are:

1. Increase the efficiency of utilization and reduce energy waste in transportation in the near term thereby giving the Nation more time to develop alternative technologies needed to change the primary energy source.
2. Identify and solve the problems associated with the use of alternative non-petroleum derived fuels. These include methanol from coal and gasoline-like fuel and distillates from coal and shale.
3. Develop new power plants suitable for automotive needs with significantly improved efficiencies and the capability to use virtually any fuel.
4. Develop technologies to permit the automobile to use energy sources stored on-board the vehicle without on-board fuel combustion.

In view of the proposed legislation before the Committee, I will address myself now to the program to accomplish this fourth and last element of our transportation program.

ERDA PROGRAM ON ELECTRIFIED VEHICLES

Since synthetic non-petroleum base fuels may not be the most energy efficient way to use our natural resources, we must also explore the option of using electricity generated from our abundant fuel resources—coal and uranium. Therefore, our plan is to develop options that will permit the transportation sector to be compatible with an electric economy, including the development of on-board energy storage systems. The storage method would be capable of being recharged from external electric sources rather than resorting to the on-board combustion process used in today's motor vehicles.

We intend to pursue research and development projects on a variety of stored energy propulsion systems including battery powered electric vehicles, flywheel powered vehicles and propulsion systems using the Stirling cycle with thermal storage as the energy source. During the course of the program we expect that additional competing systems will be studied and evaluated before decisions are made to further their development.

All projects will be integrated into an Electrified Vehicle Program whose purpose is to provide the technologies necessary to make motor vehicle transportation compatible with electricity as the energy source.

BATTERY POWERED ELECTRIC SYSTEMS SUBPROGRAM

The objectives of this subprogram are to develop and demonstrate the technologies leading to economically viable and practical vehicles capable of:

Short and medium range operation (50–100 miles practical range) [1] for demonstration in six years; long range operation (up to 200 miles practical range) for demonstration in about ten years.

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[1] The practical range is that distance expected in actual traffic conditions and not distance expected at a steady operating speed.

These objectives were formulated based on our assessment of current technologies, projections of reasonable technology advances in the future and recognition of the transportation requirements that battery powered electric vehicles must meet in order to provide a useful and competitive mode of transportation. It is important to recognize that the single most important drawback of the only currently available battery (the lead-acid battery) is its high life-cycle costs due to its relatively short life.[2] This cost factor is the main deterrent to widespread use of electric vehicles today.

We propose to pursue three parallel paths to meet these objectives:

1. In order to provide a baseline for our development programs, we need to evaluate and test presently available battery powered electric vehicles and components, including those from other countries. This information will be used as a guide to define technology deficiencies and gaps related to components and systems, and the most cost effective and energy effective areas for development.

2. The second path focuses on battery development and vehicle component improvements needed to reach a practical range of 60 to 100 miles with sufficient and economically viable battery power to permit the electric vehicles to integrate safely with gasoline-powered automobiles on the road. The advanced lead-acid battery developed specifically for electric vehicles has the potential for meeting these technical goals economically and within a short time span. Other candidates for consideration are metal-air, zinc-chlorine, nickel-iron, and nickel-zinc batteries.

Selection of specific systems for development will be made in FY 1976. The near term battery development effort goal is to extend the current energy densities of 10–15 watt-hr/lb to about 20–30 watt-hr/lb. Completion of battery development and testing with vehicle demonstrations by FY 1981 appears feasible.

3. The third path aims at developing batteries capable of providing up to a 200 mile range by FY 1986 (10 years) with performance equivalent to present day gasoline-powered automobiles. Two high temperature alkali-metal systems, lithium-sulfur and sodium-sulfur are the leading candidates to meet these requirements. Development of these two systems is currently underway both in industrial firms and Government laboratories. A brief assessment of these two systems is given in the Appendix.

We believe that electric automobiles will probably not have a major impact in this country unless advanced batteries, having lower operating cost, higher energy densities and longer life than presently available systems, are developed.

KINETIC AND THERMAL ENERGY STORAGE SYSTEMS SUBPROGRAMS

Relative to other storage systems, at the present time, the battery powered electric vehicle seems the most likely candidate for personal transportation for this country. However, we will investigate other stored energy systems.

The plan for the flywheel energy storage subprogram includes design, assembly, testing and demonstration of engineering prototype vehicles. Again we need to establish a baseline of current technologies to provide guidance for setting goals in our development program.

The thermal energy storage subprogram work will start at a more basic level than that planned for the flywheel. Research will be performed to identify substances which offer the potential of storing large amounts of energy in the solid and/or liquid states, to find ways to contain these high temperatures substances, and to investigate means to insulate the vessels to permit relatively long term storage of this high temperature source. Power plants employing the Stirling cycle appear to be compatible with thermal energy storage.

COMMERCIALIZATION OF TECHNOLOGIES

As I stated earlier, one of the objectives of the R&D program is the successful demonstration of electric vehicles showing certain proven features. We recognize that the mere demonstration of practical battery powered vehicles by Government and/or contractor is not an end in itself; rather, it is one step forward in the direction of making this new technology available to all. We are concerned about how this technology will be commercialized. Within our Division of Transportation we have established the Technology Implementation Branch whose primary function is to promote the commercialization of technologies developed in the transportation programs. As you are aware, ERDA has been given broad range responsibilities and authority to accomplish this end in Public Law 93–577, Nonnuclear Energy Research and Development Act of 1974. Use of Federal loans, joint Government/business ventures in setting up new companies and provisions for a guaranteed Government market are among the possibilities.

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[2] Vol. 1 Executive Summary and Technical Report—Impact of Future Use of Electric Cars in the Los Angeles Region. EPA–460/3–74–020–A, October 1974.

That completes my summary discussion of ERDA plans for electric vehicle research, development and demonstration and how we propose to conduct the program. Using this information as a background, I would like to proceed to express our views regarding the proposed legislation.

The objective of H.R. 5470 is to encourage and promote electric vehicle technologies and to demonstrate the commercial feasibility of electric vehicles. We are in agreement with the philosophy of developing a viable alternative to the internal combustion engine for transportation applications based on electric power sources. The change from a petroleum based transportation system to one using electrical energy obtained from coal or nuclear generating plants is highly desirable, if future transportation is to be freed from its dependence on imports or the uncertainties associated with synthetic fuels. In addition, electrified transportation could result in lower overall energy consumption, would enable the utilities to operate their systems more efficiently, and would simplify pollution control. All these considerations are persuasive arguments for the development of vehicles that derive their energy from electricity.

The emphasis of the Bill is on near-term demonstration rather than development of improved electric vehicles. A basic premise of the Bill is that current lead-acid battery technology is adequate for a limited production of electric vehicles which would be acceptable substitutes for at least some of the applications of conventionally powered vehicles. For some applications, such as urban delivery operation, this is probably true.

From the standpoint of obtaining useful range and adequate performance to allow such vehicles to mix safely with present day traffic in typical highway environments, improvements in the lead-acid battery are needed. Present lead-acid batteries have limited lifetimes. When life cycle replacement cost is included with energy cost, this results in a higher operating cost per mile than a conventional vehicle used for similar purposes, Even at fuel prices three to four times that of today. We feel that this higher operating cost would discourage the acceptance of electric vehicles. In our opinion, a minimum of three to five-year program to develop advanced batteries would be necessary to provide vehicles with lower overall operating costs and thus the ability to gain public acceptance. This is the thrust of the program which I described earlier, which is aimed at a demonstration in six years.

Section 7(a)(1) calls for the demonstration within one year of 5,000 vehicles on conventional chassis. We believe this provision of the Bill would result in a non-optimum vehicle with high life cycle costs. Such a vehicle may not best accomplish the stated purposes of the Bill.

We have already commented on our reservations about current batteries. We have additional concerns that conventional chassis would not provide the best vehicle for battery propulsion demonstration and would result in reduced driving range, drivability and convenience in quick battery exchange. Our conclusion is that the vehicles that would be demonstrated by this combination would not be capable of accomplishing the goals that are desired.

As stated earlier, we believe that any demonstration program should be delayed until battery development programs are able to provide an improved energy storage system that is more compatible with use in urban traffic patterns.

Finally, the determination of the proper size of any demonstration fleet should consider a number of factors, including the capability for producing the new technologies involved. The 5,000 vehicles specified in the Bill appear somewhat ambitious in this regard. We believe that flexibility should be retained to permit the number of demonstration vehicles to be determined as the program develops.

In summary, while we generally support the basic goals of the Bill, especially the endorsement of the need for a vigorous effort in research and development on energy storage technologies and vehicle components as detailed in Section 6, we cannot generally support the Bill. This position derives mainly from our concern that carrying out a demonstration phase too rapidly may hinder, rather than foster, acceptance of electric vehicles.

In conclusion, let me repeat that I wholeheartedly support the goal of developing non-petroleum propulsion options for transportation. H.R. 5470 recognizes the many advantages that will result from the use of electric or other stored energy vehicles. I fully agree that demonstrations are desirable to stimulate the interest of the general public. My only reservation is that in proceeding rapidly with current technology, we might not achieve the goal we both seek.

APPENDIX

There are three programs on Li/S battery development in the U.S. The largest effort is at Argonne National Laboratory; the other two are at Atomics International and General Motors. At ANL, specific energies of 68 watt-hr/lb in sealed engineering-scale cells have been demonstrated. Cell lifetimes of 2000–5000 hours with 100–200 cycles have been obtained; contracts have been let to battery firms for the development and fabrication of engineering-scale test cells. Critical areas under development are feed-through development, ceramic fiber separator, and long-life electrodes.

The Na/S battery is under intensive development both in the U.S. and abroad. Firms developing Na/S here include Ford, GE, TRW, and Dow Chemical. This system is also under development in Japan and in Europe. Testing is generally at the single cell stage in the U.S. although batteries have been tested here, in England, and Japan. Critical areas under development center about materials compatibility, seals, and inexpensive methods of electrolyte (solid beta alumina) fabrication.

Dr. KANE. The Division of Transportation is responsible for the ERDA programs to develop and demonstrate energy efficient and environmentally acceptable means of transportation. The Office of Energy Storage is responsible for programs to develop alternative methods of efficiently storing energy for application in both mobile and stationary systems. So the Office of Energy Storage has a wider application than just transportation.

I thought that before I present my views on the bill I would first provide the committee with background information on ERDA's programs in these areas. I will concentrate on that part of our program that is aimed at transportation systems, capable of being recharged using electricity. This will be followed by a presentation of our views on the proposed legislation.

I would like to start out with a few facts. Many of these are brought out in the bill itself, but I think that they bear repeating to get a real flavor for the seriousness of the problem.

Transportation, total transportation, consumes about 25 percent of the total energy used in the United States annually.

Automobiles account for more than 50 percent of the total transportation sector energy consumption.

Transportation is presently almost completely dependent on petroleum as its energy source.

We are currently importing about 35 percent of the petroleum which we consume.

All of the authoritative projections of the U.S. domestic supplies of recoverable petroleum including Alaska indicate that domestic production will drop to a small fraction of total demand sometime in the early part of the next century.

This means that, in the future, we must not only reduce energy consumption, while greatly increasing the efficiency with which we use energy in transportation, but we must also find ways to get the transportation sector off of its petroleum energy base. Accordingly, one objective of the ERDA transportation program is to develop and demonstrate the technologies necessary to markedly reduce transportation's dependence on petroleum.

In the interim, our objective is to develop technologies that will enable the transportation industry to stretch the available supplies of petroleum based fuel such that, if we must resort to synthetic fuels in the interim time frame, the vehicles available at that time will be extremely efficient.

Finally, in view of the proposed legislation before this committee, I will address myself to the part of our program that deals with onboard storage, or noncombustion transportation.

ERDA does have a program on electrified vehicles, and the reason, of course, is that the fuels that we will get in the future will come from nonpetroleum sources. It may not be most efficient to convert them first to fuel for use in the internal combustion engine. We should also explore the option of using electricity generated from our abundant fuel resources—coal and uranium. Therefore, our plan is to develop options that will permit the transportation sector to be compatible with an electric economy, including the development of onboard energy storage systems. The storage method would be capable of being recharged from external electric sources rather than resorting to the onboard combustion process used in today's motor vehicles.

We intend to pursue research and development projects on a variety of stored energy propulsion systems, including battery-powered electric vehicles, flywheel-powered vehicles, and propulsion systems using the Stirling cycle with thermal storage as the energy source. During the course of the program we expect that additional systems will be studied and evaluated before decisions are made to further their development.

The objectives of the battery-powered electric systems subprogram are to develop and demonstrate the technologies leading to economically viable and practical vehicles capable of first, short- and medium-range operation—50 to 100 miles practical range—we define the practical range as the distance expected in actual traffic conditions, and not the distance expected at a steady operating speed—for demonstration in 6 years.

Second, longer range operation—up to 200 miles practical range—for demonstration in about 10 years.

These objectives were formulated based on our assessment of current technologies, projections of reasonable technology advances in the future and recognition of the transportation requirements that battery-powered electric vehicles must meet in order to provide a useful and competitive mode of transportation. It is important to recognize that the single most important drawback of the only currently available battery—the lead-acid battery—is its high life-cycle cost due to its relatively short life. This cost factor is the main deterrent to widespread use of electric vehicles today.

We propose to pursue three parallel paths to meet these objectives. Again, of course, I'm discussing the ERDA program as it's currently planned.

First, in order to provide a baseline for our development programs, we need to evaluate and test presently available battery-powered electric vehicles and components, including those from other countries. This information will be used as a guide to define technology deficiencies and gaps related to components and systems, and the most cost-effective and energy-effective areas for development.

Our second path focuses on battery development and vehicle component improvements needed to reach a practical range of 60 to 100 miles with sufficient and economically viable battery power to permit the electric vehicles to integrate safely with gasoline-powered automobiles on the road. The advanced lead-acid battery developed specifically for electric vehicles has the potential for meeting these technical goals economically and within a short time.

Our program within ERDA on advanced lead-acid batteries also pertains to other applications and is not just for transportation alone.

Other candidates for consideration are metal-air, zinc-chlorine, nickel-iron, and nickel-zinc batteries.

Selections of specific systems for development will be made in fiscal year 1976. The near-term battery development effort goal is to extend the current energy densities of 10 to 15 watt-hours per pound to about 20 to 50 watt-hours per pound. Completion of battery development and testing with vehicle demonstrations in fiscal 1981 appears feasible.

The third path aims at developing batteries capable of providing up to a 200-mile range by fiscal year 1986—a 10-year program—with vehicle performance equivalent to present-day gasoline-powered automobiles. Two high temperature alkali-metal systems, lithium-sulfur and sodium-sulfur are the leading candidates to meet these requirements. Development of these two systems is currently underway both in industrial firms and Government laboratories. A brief assessment of these two systems is given in the appendix of my prepared statement.

We believe that electric automobiles will probably not have a major impact in this country unless more advanced batteries, having lower operating cost, higher energy densities, and longer life than the presently available systems, are developed.

I would like to bring to your attention the fact that while batteries are certainly the furthest developed energy storage concept, we propose to explore at least two other systems for storage of energy. One of these is the flywheel, driven by the advent of new, very high strength, lightweight composites, which show great promise for storing energy.

Second, we will have a program in thermal energy storage, where heat would be stored at high temperature and withdrawn for use in a Sterling-like cycle.

But I should reiterate that both of these are much less advanced, and, therefore, the chances of reducing them to some kind of practice in a short time are considerably less than those for battery vehicles.

I believe, Mr. Chairman, that completes my summary discussion of ERDA plans and how we propose to conduct the program.

Using this information as a background, I would like to proceed to express our views regarding the proposed legislation.

The objective of H.R. 5470 is to encourage and promote electric vehicle technologies and to demonstrate the commercial feasibility of electric vehicles.

We are in agreement with the philosophy of developing a viable alternative to the internal combustion engine for transportation applications based on electric power sources. The change from a petroleum based transportation system to one using electrical energy obtained from coal or nuclear generating plants is highly desirable, if future transportation is to be freed from its dependence on imports, or the uncertainties associated with synthetic fuels.

In addition, electrified transportation could result in lower overall energy consumption, would enable the utilities to operate their systems more efficiently, and would simplify pollution control.

All of these points you recognize in your bill. All these considerations are persuasive arguments for the development of vehicles that derive their energy from electricity.

The emphasis of the bill is on near-term demonstration rather than development of improved electric vehicles. A basic premise of the bill is that current lead-acid battery technology is adequate for a limited production of electric vehicles which would be acceptable substitutes for at least some of the applications of conventionally powered vehicles. For some applications, such as urban delivery operation, this is probably true.

From the standpoint of obtaining useful range and adequate performance to allow such vehicles to mix safely with present-day traffic in typical highway environments, improvements in the lead-acid battery are needed. Present lead-acid batteries have limited lifetimes. When life cycle replacement cost is included with energy cost, this results in a higher operating cost per mile than a conventional vehicle used for similar purposes, even at fuel prices three to four times that of today. We feel that this higher operating cost would discourage the acceptance of electric vehicles. In our opinion, a minimum of a 3- to 5-year program to develop advanced batteries would be necessary to provide vehicles with lower overall operating costs and thus the ability to gain public acceptance.

Section 7(a)(1) calls for the demonstration within 1 year of 5,000 vehicles on conventional chassis. We believe this provision of the bill would result in a nonoptimum vehicle with high life cycle costs. Such a vehicle may not best accomplish the stated purposes of the bill.

We have already commented on our reservations about current batteries. We have additional concerns that conventional chassis would not provide the best vehicle for battery propulsion demonstration and would result in reduced driving range, drivability, and convenience in quick battery exchange. Our conclusion is that the vehicles that would be demonstrated by this combination would not be capable of accomplishing the goals that would be desired.

As stated earlier, we believe that any demonstration program should be delayed until battery development programs are able to provide an improved energy storage system that is more compatible with use in urban traffic patterns.

Finally, the determination of the proper size of any demonstration fleet should consider a number of factors, including the capability for producing the new technologies involved. The 5,000 vehicles specified in the bill appear somewhat ambitious in this regard. We believe that flexibility should be retained to permit the number of demonstration vehicles to be determined as the program develops.

In summary, while we generally support the basic goals of the bill, especially the endorsement of the need for a vigorous effort in research and development on energy storage technologies and vehicle components as detailed in section 6, we cannot generally support the bill. This position derives mainly from our concern that carrying out a demonstration phase too rapidly may hinder, rather than foster, acceptance of electric vehicles.

In conclusion, let me repeat that I wholeheartedly support the goal of developing nonpetroleum propulsion options for transportation. H.R. 5470 recognizes the many advantages that will result from the use of electric or other stored energy vehicles. I fully agree that demonstrations are desirable to stimulate the interest of the general public. It disturbs me to take a stand against a bill whose goals are so obviously in the best interest of the Nation. My only reservation is that in proceeding rapidly with current technology, we might not achieve the goals we both seek.

Thank you, Mr. Chairman. I'm finished with my testimony.

Mr. McCormack. Thank you, Dr. Kane. We very much appreciate your testimony, and I must say I'm not dismayed by it. After all, the entire organizational structure of the executive branch came in and opposed the Geothermal bills too, but we ultimately persuaded them to join us, and I propose to do the same thing in this case.

[Laughter.]

I would like to raise a couple of questions with you.

First of all, can you document, or can you provide documentation, for your assertion that the life cycle costs using present day batteries would not be competitive, even at higher fuel prices?

Dr. Kane. We can, and for your information John Brogan, I'm sure, has that with him, if you want to probe into it now. It comes from our last study, and some other studies. Isn't that correct, John?

Mr. Brogan. Yes.

Mr. McCormack. We will see whether we have time for that. You might want to submit it for analysis. Obviously, this is going to be a matter that is going to be contested, and perhaps we would not want to try to get into a detailed technical discussion at this point, but perhaps later after we have had some opportunity for staff to analyze it. We will see how it goes.

[The information requested follows:]

LIFE-CYCLE CAR COSTS [1]

[1973 cents per mile]

	Conventional ICE subcompact current fuel prices	Conventional ICE subcompact 3 to 4 times current fuel prices	Lead-acid battery powered electric cars
Depreciation:			
Vehicle	2.3	2.3	2.5
Battery	0	0	6.4
Upkeep	2.4	2.4	1.5
Fuel	1.9	5.7–7.6	[2] 1.5–3.0
Pollution control	.9	.9	0
Financing	1.6	1.6	2.5
Taxes, insurance, parking, etc	4.3	4.3	4.5
Total	13.4	17.2–19.1	[2] 18.9–20.4

[1] The basis of this table is taken from vol. 1. "Executive Summary and Technical Report—Impact of Future Use of Electric Cars in the Los Angeles Region," EPA-460/3-74-020-A, October 1974. A summary of assumptions is attached.

[2] The 1.5 is based on 1.9 cents per kilowatthour used in the above referenced study. Current electricity (cents per mile) prices are clearly double this figure.

SUMMARY OF ASSUMPTIONS FOR LIFE-CYCLE CAR COSTS

VEHICLE DEPRECIATION

The lead-acid electric car without battery is about 30% more expensive than the conventional subcompact ($2977 versus $2270, in 1973 dollars). The basic car is assumed to cost 91¢ per pound, while its motor and controller together add $725, a figure taken from a recent Ford electric car study. This is for a conventional DC series traction motor, a conservative choice but the only one for which there is substantial automotive experience. The life of the electric car was assumed to be twelve years, 20% longer than the conventional subcompact life. The electric car motor and controller should last several times that long, with reasonable care and little maintenance, and the remainder of the car could be designed for longer life too, especially for climates where corrosion is not a serious problem. It was assumed that considerations of styling and general wear-and-tear would motivate purchase of a new electric car rather than continued refurbishing of an old car, particularly since periodic outlays of $1200 for traction batteries might make driving an outmoded car seem undesirable.

BATTERY DEPRECIATION

The 1500-pound battery of the lead-acid battery car costs $1200, or 80¢ per pound, including a 10% trade-in allowance. This price is like that charged by Sears for its 1973 automobile batteries and is below prices for long-life industrial batteries. The critical question in battery depreciation is life in automotive use. The lead-acid car would be driven less than half of its maximum range on an average day, so the question becomes one of battery life for partial discharges. This is a topic of which even less is known than battery life for full or deep discharges. The range used for lifetime—1.3 to 3.4 years—used in the referenced study reflects a range of assumptions from pessimistic to optimistic developed by a subcontractor, Minicars, in consultations with experts at ESB, Inc. For lead-acid battery of the assumed high energy density, the 3.4 year life in daily automotive use is a rather optimistic assumption. An average life of 2.4 years was used for the preceding table.

UPKEEP

A large proportion of conventional car maintenance, about 72% is indicated by current data to be associated with the internal combustion engine and its subsystems. Very little maintenance, in contrast, would be required by the assumed DC traction motor and semiconductor controller. The electric car cost includes .55 cents per mile for vehicle upkeep, .2 cents per mile for motor and controller (annual inspection, with brush replacement when needed), plus .25 cents per mile for battery maintenance (adding water to 72 individual cells as needed ten times per year). Tire and other upkeep costs are the same as for conventional subcompacts.

FUEL

The electric car recharge power was assumed to cost 1.9 cents per kW hr. a figure prevailing several years ago in California. Electricity prices have escalated very rapidly relative to other prices since that time, so this must be considered a very low figure now. Current prices of 3 to 4 cents per kW hr. would be more appropriate. The fuel consumption of the electric car, .79 kW hr/mi, is reasonable considering its 54-mile range and consequent heavy battery. On a per-pound basis, it is quite close to reported recharge energy for the highly-efficient ESB Sundancer car.

FINANCING

On the average, the electric car and its battery are more valuable than the corresponding conventional car; in fairness, the extra costs of this extra investment must be considered. Financing chages at the rate of 10% on the depreciated value of car and battery where assumed. The 10% rate is a compromise: bank loans for car and battery purchases would involve a higher rate, while withdrawals from owner's savings would entail a loss of interest at a lower rate.

TAXES, ET CETERA

Road user taxes typical of conventional car costs are assumed for electric automobiles, in fairness. Otherwise, electric autos would be given free use of roads and an implicit subsidy from motorists now paying for those roads. Most of such taxes are now collected on gasoline sales. We did not assume a specific method for equal taxation of electric cars.

Overall, the costs are appropriate to a 4-passenger subcompact electric car with 54-mile range, low acceleration performance, and minimum freeway ability. Cars with other urban driving ranges, different accommodations, or different performance can cost considerably more, or less, depending on specific assumptions. It is important to hold conditions constant in making comparisons; passenger capacity has been held constant for the accompanying table, but not performance. The conventional subcompact could achieve substantially greater gasoline mileage—approximately 27%—if its performance were reduced to the level of the electric car by a 40% reduction in typical engine horsepower. There would be resultant savings in both fuel costs and initial costs of such a lower-performance conventional subcompact.

I have another question, and that is: Since your testimony is obviously in many ways going to be contrary to much of what we expect to be hearing from other witnesses, and there will obviously be contradictory statements made, will you be able to have a member of your staff sit in on the next 3 days of hearings so that you or they can hear what the other experts have to say in this field?

Dr. KANE. Yes; we have arranged for that.

Mr. MCCORMACK. I very much appreciate that, because we have visible proof that we are moving along very rapidly in the technology—Did you have a chance to see the cars this morning?

Dr. KANE. Yes; I did and I am going to go out and check on them again.

Mr. MCCORMACK. I wonder if you were as impressed as I was.

We have the results of some very competent theoretical work behind some of these new cars, and it may have an effective impact upon your technical studies and on your conclusions to learn what's been going on. Because it appears to me—and if I was impressed by anything this morning, it was the fact that in several specific cases—I will not mention individual cars—but in several cases clearly the private sector, the innovators involved, were running away from us. Already there is at least one car down there with an electric motor in it, designed from the ground up, which would be available for production. In other words, instead of trying to buy something off the shelf and fit it to a car, we already have electric motors designed for cars, and, as you know, there is intense research being conducted in private industry on battery research. I presume you are aware of that.

Dr. KANE. Yes; we are aware of that.

Mr. MCCORMACK. And we have expected, or we have been led to believe, that there may be some positive results announced some time soon this year. This may be speculative, but at least we have been led to believe that.

So with those questions, I will turn, then, to the other members of the committee.

Mr. Goldwater, do you have a question you would like to ask?

Mr. GOLDWATER. Yes.

Doctor, I appreciate your testimony, because if we were here to have a love-fest, then there would not be any need for these hearings.

I think you have raised significant questions concerning our desire to develop an electric vehicle.

This problem of the battery I think is something that we ought to explore and find out more about. What is the state-of-the-art, and what is the life cycle cost?

In Dr. Brogan's study of the Los Angeles area, he mentioned that as the electric car comes into its own and begins to compete with the internal combustion engine in, I suppose, the year 1980 up toward the year 2000, that further refinements of internal combustion engines are not going to cause an increase, or a decrease.

The air quality in the Los Angeles area, for instance, is not necessarily going to be improved just because we're going into electric vehicles. With the improvement of the internal combustion engine the air quality is going to improve at the same time. The improvement of the internal combustion engine life cycle and the life cycle cost of batteries may make batteries not as economically attractive. In other words, the internal combustion engine is going to be competing also with the electric for a place on the road.

Is this a proper conclusion, from your study in the Los Angeles area?

Dr. BROGAN. Yes. It was assumed that there would be improvements in the energy efficiency of the conventional internal combustion powered automobiles. In fact, in the data that you have there for 1990, it was assumed that the average new car on the road would be running at about 30 miles per gallon. That's the subcompact size vehicles.

So there would be improvements. In other words, it was assumed that the new car competition gets stiffer as time goes on.

Mr. BROWN. Would the gentleman yield?

Mr. GOLDWATER. Yes, I yield.

Mr. BROWN. Mr. Brogan, I am looking at the table on life cycle car costs which is included in the Los Angeles study, and, based on the 30 miles per hour, this fuel cost of 1.9 cents per mile, which basically comes down to less than 60 cents per gallon for gasoline. You must have been projecting a 60 cents per gallon gasoline cost up into the 1990's also, which seems to me a little unrealistic.

Mr. BROGAN. The gasoline cost is the cost of the gasoline without taxes, for comparison purposes here. In this study it was assumed that one way or another, if the tax revenues are coming from motor vehicles, whether they be conventional or unconventionally powered, that as time went on local, State, and Federal governments would eventually find ways of equating the tax base on ICE cars to whatever, electric powered cars, for example.

That's why the comparison was based, not on gasoline including tax.

Mr. McCORMACK. Would the gentleman yield?

Mr. GOLDWATER. Yes; I yield to the chairman.

Mr. McCORMACK. I just want to say that I would take issue on that approach. If anything, Congress is going to do anything to stimulate any kind of transportation that does not use petroleum, and one thing it's going to avoid is putting a tax on electric vehicles.

Mr. BROGAN. Early in the game, in attempting to stimulate, electric vehicle production we envisioned just that. But as time goes on, when a large fraction of the total car population would be of the other type, electric, in this case, we did make the assumption that in one form or another the taxes would show up again.

Now, it's conceivable that that wouldn't work out that way. But it is difficult for Federal as well as State governments to accept the loss of that revenue and to write it off without coming up with some alternative.

Mr. McCormack. I don't see it happening for 15 or 20 years, at the soonest.

Mr. Goldwater. I will yield back.

Mr. Brogan. That was 1990 that we're speaking of.

Mr. Goldwater. Dr. Kane, I see some contradiction here. You are basing your premise, in your opposition to the wording of the bill, on the fact that the state-of-the-art of the batteries in essence are not far enough along to support such a vigorous demonstration act, and yet in Mr. Brogan's summary of his report on the Los Angeles area, he states that:

> The energy storage capability of even the lead-acid battery is adequate for significant urban use in the Los Angeles region, and higher energy density of advanced batteries are ample for more general use.

You also in your statement, in essence, agree that for a limited use the current state-of-the-art is sufficient.

Dr. Kane. Yes.

Mr. Goldwater. So why would we not, therefore, proceed with an accelerated demonstration if, in fact, admitting, as in anything, we are going to continue to refine a particular technology, and proceed today in demonstration and also an acceleration in research and development?

Dr. Kane. Let me try to give you as good an answer as I can on that.

Our sole objection to the bill is the timing. We do not dispute that state-of-the-art batteries can give performance in range and driving characteristics which are satisfactory for a great amount of traveling today. Our sole objection is that we are concerned that these will not be cost-effective, and the customers will buy these assuming they are.

Now, we are certainly more than pleased to hear all the latest information on life cycle costs, and we, as you say, Mr. Chairman, will factor that out in our considerations.

But, based on the information that we have, or at least when the Los Angeles study was made, major battery changes, costing the consumer a large amount of money every 2 years or so would be required. If you factor this into the total cost of operating the vehicle it wouldn't be competitive with a comparable subcompact gasoline-driven car.

Now, he still may choose to do this for a lot of reasons which have nothing to do with economy.

Mr. Goldwater. I think this is something we've got to consider because we can spend all this money on research and demonstration and then not have a vehicle which the industry can produce that the consumer will buy.

So I think, and that is the reason I brought this up, that it's important, and it's something we have got to consider.

But I would submit that by placing such an emphasis upon accelerating this whole effort perhaps will provide answers we do not have today, and that, I guess, is what we are trying to do. We, for instance—and I would ask you this question—increased ERDA's budget in the area of R. & D. in the battery development and storage of energy, and yet you are talking about a 6-year program. You're talking, as I recall, in 1981, before we will be ready to even start talking about electric vehicles and putting batteries in vehicles. One of the purposes for which we expanded and increased your money in the area of battery research is to see if we cannot collapse that time frame.

It seems to me that you should be able to, if the program is well managed. I may be overly optimistic, in not being as close to it as you are. I see that this is possible. But only if we decide that we are going to do it, and do it vigorously, and intelligently, to collapse this time frame 1981 to maybe 1978 or 1979.

Dr. KANE. We certainly will do our best, and, as the Chairman said, you are going to hear of some battery developments, which may be good news.

Mr. GOLDWATER. Thank you, Mr. Chairman.

Mr. McCORMACK. Thank you, Mr. Goldwater.

Mr. Ottinger?

Mr. OTTINGER. Thank you, Mr. Chairman.

I get the feeling with so many of the things that we do within ERDA's approach to new technologies, as it has the conservatism of the scientist approach, we never hear that anything can be done before 1980 or 1981.

I think from a scientific standpoint of research and development that frequently has merit, and I think that we have to proceed with a certain amount of caution, but I do think that we have an immediate crises in terms of our oil situation. In the great outside world the private entrepreneurs are developing things that show a great deal of promise and that deserve a more optimistic and encouraging viewpoint than that expressed by the Agency in this testimony.

How much effort have you done to take a look at the development that has taken place in the private sector in electric, steam, hybrid vehicles?

Dr. KANE. I'll have to split that question in half.

Dr. Vanderryn will answer what we have looked at in the industrial battery capability, which I think is kind of the crucial issue here. Then you can direct any questions to Mr. Brogan you want to, of course, about the vehicle part of it.

Jack, would you like to describe our battery activity?

Dr. VANDERRYN. We have consulted very widely with the battery manufacturers, and in the last year have had a number of conferences with the lead-acid manufacturers and others.

At the present time we are also cooperating with the Electric Power Research Institute. ERDA and EPRI currently have three contracts with the lead-acid manufacturers to look at improvements in that technology.

We have sponsored some design improvement studies for lead-acid systems. A workshop was held with many of the battery experts, to carefully assess the state-of-the-art. The original impetus for that was not electric vehicles, but it was to look at lead-acid batteries for load leveling on electric utilities. However, the technology improvements that are possible in lead-acid batteries would apply equally to both sectors. We're just now at the point of considering the facts that we have gathered and trying to decide what the possible improvements are, what the time scale for these improvements would be, and what the cost of development programs might be.

One of the contracts is with Gould, and Dr. David will be testifying tomorrow before the committee, and he can certainly describe their work in considerably more detail.

We also have very active programs on the more advanced batteries, such as the lithium-sulfur and sodium-sulfur systems. These, of course, we do not expect to be available on a commercial scale for a period of about 6 to 10 years.

Mr. Ottinger. On that subject, the silver-zinc battery that the Yardney Co. was producing some time ago—the Yardney Co., I think, has now gone out of existence, been absorbed by another company—had very high performance characteristics. We tried to get the Government, instead of storing its silver and paying to store it, to get some money out of it and rent it out and have it used in batteries.

Have you looked into that at all?

Dr. Vanderryn. May I ask Dr. Landgrebe on my staff to comment on that?

Dr. Landgrebe. It's too expensive for these applications.

Mr. Ottinger. It doesn't use the silver. But you'd take that out of the cost because the silver is 100-percent recoverable. Your price isn't nearly so frightening on it, is it?

Dr. Landgrebe. No; the price wouldn't be so frightening, but people probably wouldn't want to drive around with that amount of silver invested in it.

Mr. Ottinger. My thought on that is the silver is not doing anything wherever it is stored at the present time, and we are paying to store it, and the Government might very well use that silver and make some money from it by having it utilized in a way that is very advantageous to society.

Dr. Landgrebe. We've looked at material supply, even with something like lithium, that may be a problem after the year 2010. If you take a look at the amount of silver that would be required on a wide scale utilization you'd probably end up with some serious problems.

Mr. Ottinger. How many battery manufacturers, lead-acid manufacturers, are there, big and small? If you don't have it at the top of your head you might submit it—that supply lead-acid batteries?

Dr. Landgrebe. About 100.

Dr. Vanderryn. There are, I think, six large manufacturers in the country. There are many more smaller ones, of course.

Mr. Ottinger. Of the small battery manufacturers we are talking about now, have any of these manufacturers made significant advances in the state-of-the-art?

Dr. Vanderryn. As I mentioned, the six large customers are carrying out most of the research and development funded by the industry. I would say that in the past year or two they have given more serious attention to the advances that may be possible, and I think with the stimulation of ERDA activities the manufacturers are becoming more active all of the time in looking at possible advances and allocating their own funds to research and development to improve the lead-acid battery.

Mr. Ottinger. Do you systematically look at the smaller manufacturers and their work?

Dr. Vanderryn. As far as we are aware, the research and development activity of the smaller manufacturers is not very active. The industry is certainly aware of our interest, but we have not become aware of significant R. & D. activities among the smaller manufacturers. I think one would not expect a smaller manufacturer to be able to devote any significant funds to research and development.

Mr. Ottinger. I do not want to take too much time, but I wonder if you could answer the same question with respect to vehicles with electric motors?

Mr. Brogan. As Dr. Kane explained, one of the three parallel paths which we plan to follow in the program is to purchase several of the selected vehicles similar to those on display downstairs, to get a better handle on this particular problem; that is, to get a better understanding of the state-of-the-art in that area. We have not been working in that area at all. The transportation activity was transferred from EPA, and while in the EPA that was not in our charter. One of our first tasks in the new program will be to document the state-of-the-art, characterize all of the components, get a better feel for which are costly and why, and which are inefficient and why.

To complete this electric car picture, I would also like to bring out the fact that this Los Angeles study is one of three. The two others are currently underway. We specifically picked Los Angeles as the first area to investigate the electric car and its use.

We are currently nearing completion on similar studies for the cities of St. Louis and Philadelphia, real urban environments. Los Angeles isn't quite as urbanized as those other two cities.

The point behind our conducting these technology assessment studies is to better understand the consequences of our possible future actions. In other words we are examining the question "What would happen if the electric car were to be introduced in large quantities in certain sections of the country." We certainly don't want to find some snakes under the rocks 10 years from now on something that was overlooked.

When the Los Angeles study was completed, we were surprised that cost showed up as important a factor as was found. It's very important however, that we recognize this early in the game, because that tells us where we should be focusing our research, on batteries.

Mr. Ottinger. How many electric car manufacturers do you estimate that there are at the present time in the United States?

Mr. Brogan. We are aware of about 30, large and small, mostly very small firms.

Mr. Ottinger. Could you furnish a list of those?

Mr. Brogan. Yes.

Mr. Ottinger. Thank you. And the same thing with electric motor manufacturers, if you could furnish that to the committee I would appreciate it.

Mr. Brogan. Yes.

Mr. Ottinger. Thank you, Mr. Chairman.

[The information to be supplied is as follows:]

ELECTRIC VEHICLE MANUFACTURERS IN THE UNITED STATES [1]

LIMITED TO PASSENGER CARS, TRUCKS, VANS, AND BUSES

Manufacturers producing electric vehicles

Name and address	*Vehicle type and status*
A.M. General Corp., South Bend, Ind	Postal van. In production.
Battronic Truck Corp., Boyertown, Pa	Vans and buses. Limited production.
Elcar Corp., Elkhart, Ind	Two passenger. In production.
Electric Fuel Propulsion Corp., Troy, Mich.	Four-passenger conversion. Limited production.
Electric Vehicle Associates, Inc., Brook Park, Ohio.	Four-passenger conversion. Limited production.
Jet Industries, Austin, Tex	Van. Limited production.
Sebring Vanguard, Inc., Sebring, Fla	Two passenger. In production.
B. & Z. Electric Car, Long Beach, Calif	Two passenger. Limited production.
Otis Elevator Co., Special Vehicle Division, Stockton, Calif.	Van, two-passenger prototype. Limited production.
Otis Elevator Co., Diversified Operations, Cleveland, Ohio.	Buses. Limited production.

Potential manufacturers that are known to have developed prototype vehicles

Copper Development Association, Detroit, Mich.	Two passenger. Speciality construction.
Die-Mesh Corp., Pelham, N.Y	Two passenger. Prototype.
Electric Vehicle Engineering, Bedford, Mass.	Van. Prototype.
Ford Motor Co., Dearborn, Mich	Two- and four-passenger. Prototypes.
General Electric Corp., Schenectady, N.Y.	Van and four-passenger. Prototypes.
General Motors Corp., Warren, Mich	Van and two- and four-passenger. Prototypes.
Linear Alpha Corp., Skokie, Ill	Two-passenger conversion. Special order.
Pargo, Inc., Charlotte, N.C	Van. Production planned.
Waterman, C. H., Industries, Athol, Mass.	Four-passenger conversion. Prototype.
Westinghouse Electric Corp., Pittsburgh, Pa.	Van and two- and four-passenger. Prototypes.
Stuart Elektrowagon, Ionia, Mich	Two passenger. Prototype.
Chrysler Corp., Detroit, Mich	Four passenger. Prototype.

MANUFACTURERS OF TRACTION MOTORS FOR ELECTRIC VEHICLES [1]

CURRENTLY ASSOCIATED WITH THE ELECTRIC VEHICLE INDUSTRY

ASEA International, Vasteras, Sweden.
Allis-Chalmers Corp., Milwaukee, Wis.
Ambac Industries, Inc., Columbus, Miss.
Applied Motors, Inc., Rockford, Ill.
Bosoh, Robert, Corp., Broadview, Ill.
CAV Limited, Acton, England.
Electric Vehicle Associates, Inc., Brook Park, Ohio.
Electro Dynamic Construction Co., Ltd., Kent, England.

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[1] This compilation includes all manufacturers known to the staff of the Division of Transportation at the time of this hearing, June 3, 1975.

[1] This information is from the directory of the electric vehicle industry published in February 1975, Electric Vehicle News. A comprehensive listing of electric motor manufacturers which includes those manufacturers not currently associated with the electric vehicle industry can be found beginning on page 5485, "Volume 4, Products and Services" of the "Thomas Register of American Manufacturers and Thomas Register Catalog File, 1975," Thomas Publishing Company, One Penn Plaza, New York, N.Y.

Fidelity Electric Co., Inc., Lancaster, Pa.
General Electric Co., Schenectady, N.Y.
Gould, Inc., Rolling Meadows, Ill.
Kollmorgen Corp., Radford, Va.
Lansing Bagnell, Bramalea, Ontario.
Lawnel Corp., Bluefield, Va.
Magnetics International, Maple Heights, Ohio.
Otis Elevator Co., Cleveland, Ohio
Porter, H. K., Co., Inc., Warren, Ohio.
Prestolite Co., Toledo, Ohio.
Rantronics, Inc., Palo Alto, Calif.
Rogers Electric Co., Troy, Mich.
Westinghouse Electric Co., Pittsburgh, Pa.

Mr. McCormack. Mr. Harkin?

Mr. Harkin. Dr. Kane, I just want to draw your attention to page 6 of your testimony where you are talking about the most important drawback of the percent lead-acid battery is its high life-cycle costs due to its relatively short life.

In talking to some of the developers downstairs this morning, they seem to say that the life cycles of their batteries are very long. I didn't ask them how many years, but they seemed to indicate at least for the life of the car that some of those batteries would last.

Now going on from there, you say you propose three parallel paths to meet these objectives. The third path on page 7, to provide up to a 200-mile range in the next 10 years with performance equivalent to present-day gasoline-powered automobiles, and I question that that's really a valid basis. It would seem to me that you would want performance which would be compatible with present-day speed limits and driving techniques. We have 55-mile-an-hour speed limits, but we still build automobiles with 350 horsepower engines that can go beyond 130 miles an hour. We have high traffic densities in the cities, and yet automobiles are built that go from 0 to 60 in 4½ seconds, and you never get to 60.

So I'm wondering if that's really a valid basis.

Dr. Kane Your point is very well taken. I don't see how I could argue with you.

To make the total performance envelope comparable to, or compatible with, today's automobiles would not be an intelligent goal.

Mr. Harkin. So it would be compatible with the new driving techniques, new speed limits, and so forth?

Dr. Kane. Yes.

Mr. Harkin. In other words, compatible with the total energy conservation?

Dr. Kane. Yes; the main problem, I believe, is the range. It will probably be a long time before Americans give up things like vacations, where they like to drive an extended range. That's really our point, and I think you've done us a favor in clarifying this.

We certainly don't need rapid acceleration and high ultimate speed.

Mr. Harkin. OK. I just wanted to make sure you weren't using that as a basis of your evaluation in the future, because that would tend, I think, to put it up to a long period of time to try to develop something like that.

Dr. Kane. That is correct.

Mr. Harkin. Thank you.

Mr. McCormack. Thank you, Mr. Harkin.

Mr. Thornton?

Mr. Thornton. Thank you, Mr. Chairman.

I do appreciate your testimony today, and I think it is very good that you brought to us certain of your concerns about this development, which all of us, of course, would like to see move forward as quickly as possible.

However, I think before we begin to sail on a sea that we're going to try to travel that it's well to have pointed out to us what some of the reefs and shoals might be, and I think that's what your testimony has attempted to do.

Particularly I am concerned about the necessary assumption if we are to achieve savings in oil and gas by means of electric cars that we must also proceed immediately to the development of nuclear resources for generating electricity, and for coal-burning resources, because, if I understand your studies correctly, the electric car uses more oil, more gas than conventional internal combustion engines would use for the same performance, if oil or gas is the fuel for power generation, and the loss occurs therein, through the transmission, to the homes in the recharging. Is that correct?

Dr. Kane. That's a subject of much controversy. I believe I cannot say that's correct. It's debatable which is the more efficient route to go. I think with today's automobiles the electric car on total efficiency might win out, even though you use oil and gas as a source of the electricity. That's with today's car, which is very inefficient.

Certainly, in the long run, to get away from oil and gas entirely is the way we want to go. There's no question about it.

Mr. Thornton. The point I am trying to determine by asking these questions is whether, unless you go to nuclear or coal-fired generating facilities, you will be achieving a major savings in oil and gas by going to electric-powered cars under existing technology.

Dr. Kane. That has so many aspects to it that it's a very difficult question to answer.

Mr. McCormack. The point Mr. Thornton is making is well taken. Obviously, you have to generate electricity; and using petroleum-derived gas, you just said it's a controversial point as to which way is more efficient. If you go to nuclear, you're obviously saving petroleum.

Dr. Kane. Yes; no question.

Mr. Thornton. That is precisely the point.

As a matter of fact, on page 7 of this Los Angeles study, it appears that the relative overall energy consumption in terms of Btu/mile on a lead-acid battery automobile is approximately, if I can read these charts correctly, 8,300 Btu per mile, as compared with the Ford Pinto in the range of some 6,000 Btu per mile; the Honda Civic around 4,300 Btu per mile; and if the energy required is generated by oil or gas it would seem to me, and if the figure is correct, that it becomes clear that you must go to nuclear or coal-fired power production in order to achieve a savings in oil or gas, and that assumption, I think, is made in this study which you have made.

I think it needs to be pointed out to all members of this committee that merely by converting the automobile fleet to electric power we would not accomplish oil and gas savings unless we also continued to develop alternative sources of power generation for the electricity itself.

Dr. KANE. Yes, I concur.

Mr. THORNTON. Thank you, Mr. Chairman.

Mr. McCORMACK. Thank you, Mr. Thornton.

Mr. Fuqua?

Mr. FUQUA. Thank you, Mr. Chairman.

Dr. Kane, I think I can say, as many others have, that you have pointed out some very interesting areas that we should concern ourselves with. Particularly the limitation of the present day state-of-the-art batteries.

What is ERDA doing in that direction? You mentioned it in your statement just casually, but how much money is ERDA putting into new and improved battery research as an alternative source of energy?

Dr. KANE. I'm going to refer that to Jack Vanderryn here. But I would like to point out that we are interested in batteries for a number of applications in addition to transportation.

Jack?

Dr. VANDERRYN. Yes. We're spending approximately $3.7 million in this fiscal year on battery research. That will increase markedly next year. Of course, we do not know yet what our fiscal 1976 budget numbers will be.

Mr. FUQUA. It appears—and I regret that I was called out to the phone when Dr. Roan had completed his statement—but it seems, as an interim phase, that it would be very important to have the hybrid system that he was referring to as an interim system to get better length, acceleration, and so forth, until such time as we have a better battery.

Would you concur with that?

Dr. KANE. Without pretending to be an expert on hybrid vehicles, certainly, as Professor Roan pointed out, the virtues of them are that it allows an internal combustion engine to run at its optimum performance, and an engine running at optimum performance is really far more efficient than one that surges and accelerates, and all that.

Also, I believe—and John will correct me if I'm wrong—that the hybrid is less demanding on battery performance. It can function with a less high quality battery.

The reservation that I have pertains to the complexity and cost of control systems and how much it will cost to manufacture a hybrid vehicle at a competitive price. I confess that I do not know the answer to that. I merely raise it as a question.

Mr. FUQUA. I think that is something we should look at though as an interim stage, until such time as maybe we do have the other battery.

It was just pointed out to me that ERDA requested $9.1 million and the committee increased that to $13.832 million for energy storage systems. So I hope that you will put some more money into batteries.

Dr. KANE. We're very grateful, and we fully intend to put it in.

If we were to get that much, Jack, could you give us what the potential split on that is? It's largely batteries, isn't it?

Dr. VANDERRYN. If we have a $30 million budget, as I recall, the expenditures on batteries would be approximately one-third or about $10 million.

Mr. Fuqua. I just wanted to point that out for Dr. Roan's benefit, so that he can put in his application, if it's not too late.

[Laughter.]

Thank you, Mr. Chairman.

Mr. McCormack. Thank you, Mr. Fuqua.

I might say that I think you're going to get most of that money, by the way.

Mr. Goldwater. Mr. Chairman.

Mr. McCormack. Yes, Mr. Goldwater.

Mr. Goldwater. May I point out that in 1976 we authorized some $18 million in this particular area.

Mr. McCormack. That's for 1976.

Mr. Goldwater. 1976.

Mr. McCormack. Actually, we have two areas here. One is energy conservation as such and one is energy storage as such. So actually we have two pockets to draw from, I believe.

Dr. Vanderryn. Well, energy storage is part of the total energy conservation program.

Mr. McCormack. And solar storage is second, and then advanced transportation systems.

Dr. Kane. Most of the storage work in ERDA is going on within conservation, specifically, under Dr. Vanderryn. We have all sorts of arrangements with the solar people to make sure we're not doing the same thing twice. Their needs emphasize more, as you would expect, thermal storage.

Mr. McCormack. Yes, I understand.

Mr. Goldwater. If we increase the energy storage by $18 million, which would almost double.

Mr. McCormack. That would be $30 million.

Dr. Kane. That's the assumption Dr. Vanderryn made, that it was $30 million.

Mr. Goldwater. And the power systems would be increased by $13 million, and then add to that about $9 million, you're looking at a considerable amount of money here.

Dr. Kane. Yes. And I'm sorry to split it up between storage and the vehicle part. These two gentlemen do work together.

But our program in the vehicle aspects of it are going from about $1 million to several times that much, four or five times that much.

Mr. McCormack. Thank you. We'll be planning to get back with you in the fall.

Mr. Goldwater. Does that mean you've hired more people?

Dr. Kane. That means we're in the process of hiring more people.

Mr. McCormack. We expect we'll be getting back with you in the fall and having a review and see how well you're doing.

Mr. Blanchard?

Mr. Blanchard. Thank you, Mr. Chairman.

Dr. Kane, when did you become Deputy Assistant Administrator for Conservation with ERDA?

Dr. Kane. I started as acting when the agency was formed. That would have been the 19th of January. I was made the permanent Deputy around the middle of March.

Mr. BLANCHARD. How deeply involved were you in submitting the budget, the ERDA request, this year?

Dr. KANE. The 1976 budget request of ERDA, which was forwarded to Congress, was in large part made up before ERDA was formed. You know the sluggishness of the budget cycle. So a straightforward answer to that is that when the budget was forwarded to Congress, I had essentially no part in its formulation.

Mr. BLANCHARD. I was just curious, because you were talking about conservation, and the President talks about conservation, and all of us were a little stunned when we saw the budget that less than 1 percent of the ERDA budget is devoted to conservation, and we're kind of putting you on a spot by requiring you to come in and talk about one element of it, when it appears that only a small part of your work is directed at it, and its perplexing to me, and I'm sure to other members of the committee.

Dr. KANE. Yes; my rejoinder is that I appreciate your concern for the attention being, or not being, given to conservation, and this does have the attention, right up to Dr. Seamans' level. He is very concerned that it's low too.

Mr. BLANCHARD. I have no other questions. Thank you, Mr. Chairman.

Mr. MCCORMACK. Thank you, Mr. Blanchard.

Mr. Hechler?

Mr. HECHLER. Dr. Kane, I appreciate your calling the attention of the committee to how we have to be realistic and practical and feasible in all of our discussions in this area.

I personally—and several members of the committee have mentioned this—would feel more comfortable if ERDA came in and said to Congress, "your timetable that you are proposing is a little bit too long," and lean on us a little bit to try to speed it up.

In that context, I remember a President of the United States some 25 or 35 years ago saying that America needed to produce 50,000 planes a year, and the reaction of the industry at that time was one of great shock. They said they couldn't do it, and that President then said, "Go back and sharpen your pencils," and we not only produced that many; we produced twice as many.

The point I would like to make is that the situation is reversed here. We do not have a reluctant industry that says that it cannot do these things. As a matter of fact, the industry itself wants to move faster, and it is in that context that I hope that you will continue to try to, as Mr. Goldwater said, "Collapse the timetable"—I say compress the timetable—to such an extent that we can achieve these objectives quicker.

Dr. KANE. We'll certainly do our best, and I hope that my testimony today did reflect my enthusiasm for the goals that you've set up. There's just no question in my mind; we support them entirely; the goals of this bill.

I've tried my best to be realistic about some of the pitfalls.

Mr. HECHLER. One further question: In your analysis, which is largely devoted to R. & D. and to propulsion and cost-effectiveness, have you geared in questions of safety in connection with R. & D.

Dr. KANE. John Brogan.

Mr. BROGAN. Yes; this gets back to that initial assessment of the roadgoing vehicles. We will be working with the Department of Transportation and the National Highway Safety Administration on this. We have had discussions on that.

One of your points brought out in the bill was the safety aspects of these vehicles, and we have had discussions with the Department of Transportation personnel, in regard to possible need for exemptions to some of the safety regulations for, let's say, vehicles that might not run on freeways, for example. There are many kinds of exemptions that are possible and this has been done in other areas.

Some of the electric vehicles on display downstairs, have had some certain safety exemptions allowed, because of the small number of vehicles involved.

Mr. HECHLER. Would you, Dr. Kane, elaborate, just in a sentence or two, on the statement that you ad libbed? On page 7, when you were discussing batteries, you added a sentence that was not in your prepared testimony that the R. & D. was going on in other than transportation usages, and I wonder if you would elaborate on that?

Dr. KANE. Yes; under Dr. Vanderryn here we have a broad energy storage program. The storage of energy for later use is a valuable technology to have available for a variety of applications including for instance, the heating and cooling of buildings. It's valuable in transportation, which we're talking about. It's also very valuable to the electrical generating industry. The electric automobile will help the electrical generating industry by increasing the demand at night. So this storage program encompasses applications for all systems.

As Dr. Vanderryn said, our next year's program, if the total is $30 million, about one-third of that will be directed toward batteries. The other two-thirds will be applied to various ways of storing energy, for the utilities, for use by solar energy people, and by use in housing, industry, and transportation.

Mr. HECHLER. Thank you.

Mr. MCCORMACK. Mr. Brown, I think you had to skip out on us for a time, but we are glad to have you back and have you take a turn. Particularly, I wonder if you could tell us anything about Mayor Bradley.

Mr. BROWN. I'm sorry that Mayor Bradley, I've just learned, will not be able to be here. However, he will submit a statement for the record, which will be available to us. He has the normal problems of big city mayors trying to get their budgets passed this time of year, and is unable to be present.

I wanted to explore one other line of questioning just briefly if I might, Mr. Chairman.

Mr. MCCORMACK. Be my guest.

Mr. BROWN. Before I left, I started to go into some of the assumptions that were involved in the southern California study, which I thought in general was an excellent study of electric car potential, and undoubtedly one of the best ones we've had to date.

But in addition to the cost aspects, which I think will need to be reviewed and scrutinized very carefully, you had certain assumptions in there with regard to the emissions effect of using the electric vehicles, and I wondered again if you might elaborate a little bit on the assumptions which underlie the study from the standpoint of emissions, because since the study was made the Environmental Protection Agency and the administration have changed their attitude toward the requirement for catalytic converters. They are proposing a considerable stretchout in the emissions standards, and this will have, of course, its most important impact on the southern California region, which is the most subjected to automobile emissions.

So in the light of these changes, or potential changes, which the administration is supporting, I wonder if this would affect the results of your study on the contribution of electric vehicles to the emissions in the Los Angeles area?

Dr. KANE. I believe I would turn that over to Mr. Brogan, since he's more familiar with that study than I am.

Mr. BROGAN. Yes; things are advancing rapidly in that area, and there have been a number of other things that would bear a second look since that study was made.

I point out that our President has asked that by 1980 there be no more petroleum-fired electric utilities, and if that does hold, that would influence the results of the study, in particular in the Los Angeles area, because many of the electric utilities are still using petroleum. In other words, that source would be removed, and others, perhaps coal, would be used in its place.

So that could stand updating. No question about that.

The other basic assumption made was, as you stated correctly, that automobiles on the road produced after, I believe it was 1976—would be meeting the standards required in the Clean Air Act amendments, and so, in the vicinity of 10 million new cars per year, starting in that model year, and essentially all the cars on the road in the Los Angeles area, as it turned out, by 1990 would be relatively clean cars.

The direction that things are going now is rather confusing. It isn't clear whether the sulfate issue is real, or to what extent it is going to influence decisions in regard to the standards.

I do agree, at any rate, that there is a need for updating the air pollution part as soon as some of the assumptions made can be firmed up. The general conclusion, however, was that there was only a very minor change in air quality, with all those assumptions built in.

Mr. BROWN. Yes; I am aware of the conclusion, and I just question whether or not the conclusion would hold, given the change in the basic assumptions which may have to be made.

Mr. BROGAN. It is going in the direction of favoring the electric cars, if that's what you're getting at.

Mr. BROWN. I think both the emissions criteria and the economic criteria if updated might indicate a more favorable experience for the electric car.

You may have touched on that while I was out.

Mr. BROGAN. Yes.

Mr. BROWN. I have no further questions.

Mr. MCCORMACK. Thank you, Mr. Brown.

I have a couple of questions, Dr. Kane.

You stated that your sole objection to the bill was timing, and then later on in responding to another question you said something similar to this: That you support the general strategy of this bill for demonstration.

May I just ask again, I take it that since you have stated that your sole objection to this bill is timing, that this would infer that the general strategy for a demonstration outlined in this bill is a good one from your perspective?

Dr. KANE. I think my general answer to that is "Yes." My considered answer, I'd like additional time to go through it.

I also want to point out that this is a judgmental thing. The possible harm that could be done by early introduction if it turned out to be non-cost-effective must be weighed against the possible advantage to be gained by early introduction. I think that's a judgmental matter, and not scientific.

Mr. MCCORMACK. Let me introduce one other thing for your consideration.

Mr. Brogan has talked about finding the snakes first, and I very much agree with this, of course. This is one of the things we are after in a demonstration program is to find all the bugs in a system, whereever they may be, whether they are in the manufacture, or use, or whatever.

But does it not make sense to do that as soon as possible if one can do it with leased cars? After all, the concept of this bill is to lease the cars out, for ERDA to buy them, to set up performance criteria, to buy the cars and then to lease them out for a year. Now, this implies no hazard, no economic hazard, to the lessee.

Dr. KANE. Yes.

Mr. MCCORMACK. And yet, at the same time if we were to do this, let us use, for example, 10,000 vehicles. You would have perhaps 20 of them in every congressional district. There's a simple mechanism for getting them distributed. We might have a lottery in every congressional district, and the 20 winners get to lease a car. Now, you have pretty good geographical distribution in every area of the United States: in northern Minnesota, in southern Florida, in the mountainous country, in the deserts, every place else. You have electric vehicles out there on a leased basis being tested out for a year, and they're out there because the cars that are out there have been produced by private entrepreneurs competing, obviously, for public favor, trying to get the best product out, so they can be doing their very best to do a good job, to get their vehicle out there.

Doesn't this technique, particularly using leased cars, lend itself to moving more promptly, than just trying to make them and sell them?

Dr. KANE. Certainly by doing this you reduce the danger of antagonizing someone by subjecting him to a lot of extra costs that he hadn't anticipated.

But, Mr. Chairman, there may be other aspects of the timing which are unrealistically short. I would like to respond to that question in two ways.

First, by leasing, you certainly have removed an impediment, in that you're not going to penalize someone who's bold enough, or patriotic enough, to come forward and take a step up.

This leaves us with a second question. Namely: What timing would be proper for a leased program. I would like a little more time to study this question before taking a position.

Mr. MCCORMACK. I appreciate that, and I would appreciate your future comments on it.

Incidentally, however, I do want to say that I have seen television commercials where somebody drives up to the curb in a new car and he immediately is surrounded by a whole bunch of admiring, drooling people who happen to be standing there nearby looking at the car, and saying, "Isn't it wonderful?"

Well, I had an opportunity to drive an electric car recently and the very same thing happened, not to me but to the car, you understand. [Laughter.]

But literally when we stopped the car we were surrounded almost immediately by pedestrains who happened to be in the vicinity, and they came running up and said, "What's that? What's that?" And they wanted to see it, and they asked "How much does it cost, and where can I buy one?" I think the fact is we would have to beat them off with clubs if we initiated any sort of a lottery, with any one of a dozen lotteries that could be available within a short time.

I do not expect you to comment on that, but I did want to make that observation.

Let me ask you a couple of other quick questions with respect to your testimony.

One of them is that you said you thought perhaps 5,000 cars, I believe you said, might be too ambitious. Let me consider that with you for a second, and ask you to consider this thought:

Since this is really a program in which ERDA would be setting performance criteria and purchasing the vehicles from private manufacturers who bid in, based on the performance criteria, and suppose we had a requirement that no less than 500 and no more than 1,000 cars could come from any one manufacturer, so you would have 10 to 20 manufacturers involved, is it any more ambitious to talk about 10,000 cars than 100 cars? After all, in your managing the program it would take very little more management to have contracts for 500 to 1,000 cars than for 10 or 20 cars, except for the number of dollars involved. I'm completely convinced the people in this country would completely support such a program in exchange for the information and the opportunity to have a chance at the cars?

I'm curious to know why you think a larger number of cars, the figure 5,000, is more ambitious than 100 cars, if we're going to get them under those conditions.

Dr. KANE. I think that had two parts, and I may give the second part to John here.

The first part, if we delayed until more advanced batteries were in—and by that I don't mean the truly advanced batteries, but the interim batteries—we are concerned about the availability of sufficient production capability to produce this number of, say, advanced lead-acid batteries. That was one aspect.

The second relates to the availability of components. We haven't looked at that in detail yet. We were just asking for discretion in case they weren't available.

John, do you have any further comment on that?

Mr. BROGAN. Yes, I do.

On the one hand you're sincerely trying to help the small businessman and the entrepreneur. In a case like that, perhaps it would be helpful to the entrepeneur to stagger this somewhat, in smaller quantities. To produce 5,000 vehicles requires a large investment in tooling, people, and facilities, in a short time period as required in the proposed legislation. This would be different even if it could be accomplished outside of the auto industry. So I can see a need for staggering, for example, a first buy of 50, the second buy 6 months later of 100, and then increase it, et cetera. That, or something on that line, could permit the small businessman to tool up without spending money extravagantly in the process. So that's one point.

The other point is whether the 5,000 is an arbitrary number. The more the merrier, in one sense, if you could get more information. I'm not sure whether 1,000 isn't as good as 5,000 in this case, whether that much more will be learned from 5,000 as opposed to 1,000. That would be my only concern on quantity.

The other point, though, is that first demonstration.

Mr. McCormack. After 18 months?

Mr. Brogan. Yes; that's what it was. The first demonstration was after, I believe, 12 or 18 months. There would be 5,000 of these cars on the road. It takes time to define a set of specifications that are meaningful and that can be lived with, and then get the procurement action going, get the proposals evaluated from all the many—I mentioned 30 firms—maybe 30 different proposals. It takes time to go through the procurement process, and arrange then, for all of the contracting.

Nothing's impossible in this day and age, but from my experience in government, I find that these things take time to accomplish; especially if you want to spread the contract awards out among many small firms.

Mr. McCormack. I'm sure we appreciate that perspective.

We don't consider the legislation frozen in concrete as it was written. We're trying to improve on it, and certainly nothing in our legislation, or in our minds, would preclude buying progressively from a manufacturer, 50 one month, 100 another month, and so on, if this happened to make sense.

I think what we are really concerned with in the bill is, again, as with the solar heating and cooling bill, to sort of push everybody off the diving board at once, and the reason for this large a number is because we're thinking about the entire country, not just Washington, D.C., not just ERDA, and not just the Congress, but the entire country.

After all, one of the things we have to do is to demonstrate to the average citizen, who is not sitting in this room, that an electric car is a practical alternative for a second car, that it can be used to run the normal errands that you run every day, and that seeing this in these home towns, physically seeing someone doing it, is the kind of demonstration that has an impact.

So I don't think we're in disagreement, but we appreciate your comments there, and I think we will probably, as we write the bill, be coming back to you asking for suggestions as we write the final version, particularly in terms of establishing schedules, performance criteria, and purchasing procedures, so that we do not put you in the position that you can not handle the situation in managing the program, and so that we can move it forward as rapidly as we can.

One other point that you made, Dr. Kane is, I think, a major conservation aspect in this bill. That is, if we're charging up these cars at night, and that is another factor, that the charging devices, we can put a requirement that they be charged only at night, for domestic purposes so that they would not be providing an additional load on your electric utilities, but would, in fact, be making our whole electric system more economic. I think this is a significant conservation factor.

Dr. KANE. It's truly enormous. I wish I had the precise numbers to give you, but roughly, the American system of generating and distributing electricity runs on the average at half its maximum capacity. That means that the wires leading out are all oversize, and sometime generators are standing idle, or running below their capacity. But essentially what you people are doing with this electric car bill is to mandate a type of electric energy storage where you could store energy in off-hours, for use at a later time. It would make a very large contribution. In terms of capital saved, it offers the potential for saving hundreds of millions of dollars on the capital cost of the system.

Mr. MCCORMACK. Thank you, sir.

Does anybody else have any questions? Mr. Hechler?

Mr. HECHLER. I was just going to suggest, since Dr. Brogan is concerned about the snakes under the rock, that we call the first electric car the mongoose. [Laughter.]

Mr. MCCORMACK. Mr. Goldwater?

Mr. GOLDWATER. Mr. Chairman, one comment, perhaps, for clarification.

I'm sure the chairman didn't intend this to define the purpose of the bill. It's my impression that the purpose of the bill is not necessarily, although it may be an indirect benefit, to demonstrate electric cars to consumers, or to convince Americans that it is a viable product.

It seems to me, if I'm interpreting the purpose of the bill, and the purpose of the chairman, it is to demonstrate the state-of-the-art. The state-of-the-art, when coupled with a vehicle will either sell itself or it won't. It will either be competitive, or it won't. Am I correct?

Mr. MCCORMACK. I do not think we differ on that. It is very obvious to me that we need to make the American people aware of the fact. It is not a matter of trying to persuade them. I think it is a simple matter of making them aware of the presence of electric cars that will do the job is all we have to do.

Mr. GOLDWATER. But that is not the purpose of the bill.

Mr. MCCORMACK. That is part of the purpose of the bill, as I see it. The other part is the stimulation of industrial participation in research and development. There are many purposes.

Mr. GOLDWATER. It appears to me that the primary purpose would be to demonstrate the state-of-the-art, and then a spinoff would be to demonstrate to the American people, and we are talking here about managing a lot of money and, in essence, a new program, and I think your contribution here Dr. Kane, has been helpful in exploring what's the proper way and the proper approach to manage this.

We have not had, I think, sufficient time to go in depth into your thinking as to an alternate approach to just calling 5,000 cars within a certain period of time.

Some of the points you have made may be valid, and I think it would be helpful to this committee if you could go back to your drawing board and explore this.

Basically in your testimony you object to the approach of the bill. You do not object to the intent, but you object to the approach. Basically, it was an objection on when, or the timeframe that we do it in. You did not discuss at all how we are going to do it, how we are going to manage it. I think that would be very helpful to this committee, because I can assure you this bill will become law, and you would have the responsibility of managing the program. So I think it would be helpful to address such things as the part small business is playing in this program, their protection, their patent problems, their participation, how much participation. Most of the inventions in this area have been by small businessmen, and there should be some protection. There should be some allowance for participation and for continued input, changes in regulations and consumer acceptance.

The form of the bill, in essence, is what we are looking at here. It's not necessarily a side show to promote the luxury car as much as it is a serious discussion on how this program and how the bill will be formulated to come up with a good program that you can manage, and so I think that input would be very helpful.

So instead of just addressing yourself as you did to the time frame basically, I think you should address yourself to the management of the program and, in essence, how we are going to do it. If you could do that I think it would be very helpful to the committee if you would submit this to the committee for our consideration, because, as the chairman said, this is not locked in cement. We want to have the best program.

Dr. KANE. We will certainly take your advice and do the best we can to make constructive suggestions.

Mr. GOLDWATER. I want to say I've been very much impressed with Dr. Kane and his associates. It's been refreshing testimony, inasmuch as the testimony has been very frank and very honest, with open admissions that there is more than one way of doing things, and I want to thank the doctor for being here.

Dr. KANE. Thank you.

Mr. MCCORMACK. Thank you, and I want to thank you for your comments, Mr. Brogan, and I really associate with your comments.

I very much appreciate the opportunity of continuing to work with you, Jim, and your staff, and we look forward to it on a continuing basis.

[Answers to additional questions submitted to Dr. Kane follow.]

Response to Questions Posed by Congressman McCormack on Proposed Legislation H.R. 5470 - The Electric Vehicle Research, Development and Demonstration Act of 1975

The response to these questions should be placed in the proper context. The Energy Research and Development Administration (ERDA) is on record as opposing the proposed legislation. The following excerpts from Dr. James Kane's testimony on the Bill aptly summarize the ERDA position.

- A basic premise of the Bill is that current lead-acid battery technology is adequate for a limited production of electric vehicles which would be acceptable substitutes for at least some of the applications of conventionally powered vehicles. For some applications, such as urban delivery operation, this is probably true.

- From the standpoint of obtaining useful range and adequate performance to allow electric vehicles to mix safely with present day traffic in typical highway environments, improvements in the lead-acid battery are needed.

- Because of short battery lifetimes resulting in high life-cycle electric vehicle costs improvements in battery technology must occur before electric vehicles have a good chance of being economically competitive with current automobiles.

- Until these developments are realized it would be premature to mandate a large and costly demonstration program designed to show the attractiveness of the electric vehicle option.

- In our opinion, a minimum of three to five-year program to develop advanced batteries would be necessary to provide vehicles with the ability to gain public acceptance. This is the thrust of the ERDA's program which is described in earlier testimony.

Q.1. Is there a need for a federal role in aiding the Electric Vehicle industry? Please give detailed, supporting arguments.

R.1. There is a need for a federal role with respect to the fledgling electric vehicle industry. This need is based on:

- The potential nationwide impacts that widespread use of electric vehicles would have on social, economic, environmental and energy aspects of living in the United States.

- Adverse effects on the balance of payments problem could result where foreign produced EV's become an accepted part of the marketplace.

- The widespread use of EV's in this country appears to be one means of converting the most heavily petroleum energy dependent element of the transportation sector, the automobile, from petroleum energy to coal, solar and/or nuclear energy sources available in abundance domestically. Some effects of this switch in energy sources include: less reliance on unreliable foreign petroleum sources of supply; a stronger position in foreign affairs and strengthened national security.

Q. 2. Are the timing of the procurement, and the characteristics of the vehicle called for in the bill reasonable?

a) Are these provisions feasible given the current state of the industry?

b) Will they truly promote implementation of electric vehicle (EV) technology, and avoid "locking in" obsolete ideas, or dead-end lines of development?

c) Should there also be a fixed deadline prototype development program, to promote advanced-type electric vehicles?

R. 2. a&b The procurement timing in the proposed legislation appears to be too short in that there is insufficient time to implement the first "buy" within one-year after enactment. Similarly, the second "buy" within three years does not provide enough time to apply what might be learned in operating the first series of EV's. Finally, both proposed "buys" lock-in use of existing technologies (at the start of the program) because there is insufficient time to develop and commercialize any significantly new technology. The production of 5,000 vehicles within the first year, whereas perhaps feasible for the industry, would certainly limit the options of vehicles and manufacturers that could enter the program since little time would be allowed for tooling and preparation for production.

In regard to vehicle characteristics the restriction to use conventional chassis as specified in the Bill is not desirable since their use on EV's make battery exchange difficult. In addition, such a chassis is considerably heavier than needed for EV's. This means a reduced driving range and poorer road performance.

c. Finally, in our judgement, use of fixed deadlines as appearing in the Bill limits the exploitation of technical options that normally develop in R&D programs.

Q.3. What are the best means of procurement for vehicles in order to insure that a fair mix of companies will be able to participate?

a) Will low-capital companies be able to compete in straight competitive bidding, in the sense of being able to finance their bids against possible future sales and subsequent recovery of set-up costs?

b) Would loan guarantee provisions better enable such companies to raise needed capital?

c) Will patent provisions, delivery schedule, or contract penalty provisions inhibit particular kinds of companies from participating?

d) Should there be a specification that fixed numbers of vehicles must be supplied by companies less than a given size -- and/or that fixed numbers of vehicles in given price ranges should be purchased -- in order to ensure participation by a broad range of companies?

e) Would excessive reliance on small business tend to waste the productive capacity available from the large auto manufacturers, and unnecessarily increase costs of initiating a strong electric vehicle industry?

f) What change in safety or import regulations may be necessary to enable a variety of companies to participate?

R.3. The impacts of various measures on the ability of companies to compete are delineated below:

a. Small low-capital firms, typical of the current EV companies, have limited ability to amortize engineering, tooling, and other start-up costs against future sales. In addition, their cost estimating would probably be more conservative and thus less competitive on a bid basis. A large company desirous of ensuring a future place in the EV market by amortizing start-up costs over future sales likely would have a competitive advantage.

b. Loan guarantee provisions may help small companies raise needed capital. Small companies with poor fiscal records probably would not be aided by any form of loan guarantee provisions.

3c. Patent provisions are generally of concern only in development programs where government funds are expended to invent or improve design features. Patent provisions should not be an inhibiting factor if EV procurement were to be kept separate from EV R&D efforts. Delivery schedule and contract penalty provisions may tend to inhibit some companies from participating in an EV procurement program. Some companies may feel that the penalty for non- or late performance could be an excessive risk in terms of loss of their business in event of default. Some meaningful form of control over the contractor (e.g., non-payment of contract funds, etc.) would appear necessary; otherwise, the program would not be manageable and there would be no real guarantee of eventual program completion.

d. Specifying fixed numbers of vehicles to be procured from smaller companies and/or fixing price ranges pose several problems. For small companies, the number of EV's procured should be large enough to keep unit vehicle cost down, while on the other hand, the number should be low enough to assure adequate confidence that the company can, in fact, manufacture the vehicles in accordance with schedule requirements.

e. If carried to the extreme, excessive reliance on small businesses could be wasteful of the productive capability of larger manufacturers, and at the same time increase the costs of initiating an electric vehicle industry. However, it may be desirable to give the smaller firms some advantage so that good ideas or design innovations do not get submerged by cost considerations at a time when technology advancements may be most important. In some cases a smaller company may procure parts (e.g., body frames, batteries, controls, etc.) from larger firms and then act as a "systems integrator" in final vehicle assembly. It would appear that excessive reliance on small businesses could increase the cost of getting the new industry started.

f. Since EV's generally do not match the same road performance of the conventional automobile one would expect that exemptions may be necessary on the basis of inherently limited performance characteristics and perhaps, restrictions of use in the demonstration, e.g., prohibiting their use on interstate highways. Such considerations by DOT coupled with these restrictions on the part of the user would help the EV's in their initial role as replacements for conventionally powered second cars.

Q. 4. What is the long-range environmental implication of electrification of transportation?

a) Does an implied centralization of energy production have negative as well as positive ramifications? How do these balance against elimination of mobile combustion pollution sources?

b) What are the short and long-term alternatives to transportation electrification?

R. 4a. Centralization of energy production can have negative as well as positive ramifications. On the negative side, we recognize that there would be increased thermal pollution (for cooling water), SO_2 and fine particulates if coal were to be used as the energy source. On the positive side, it is possible to more easily confine these problems to areas where there are fewer people. A study was recently made regarding use of EV's in the Los Angeles area in which it was found that the widespread use of the EV would not appreciably affect photochemical smog formation compared to conditions arising where the ICE would be controlled to meet Clean Air Act standards. However, it should be easier to control emissions from electric power plants with slow operating transients than from a vast multitude of individual sources operating on a transient basis with relatively poor maintenance procedures as in the past.

4b. With respect to the environment, in the short term the primary alternative appears to be a vigorous enforcement of the Clean Air Act Emissions and Air Quality Standards. In the very long term, the alternatives include either the use of alternatives which use thermal and mechanical energy storage, or efficient heat engine (on-board combustion) powered vehicles using hydrogen as fuel derived from the electrolysis of water.

Q. 5. Will provision of maintenance facilities for electric vehicles be a major problem in their wide-spread adoption?

R. 5. Maintenance and recharging facilities could be major problems in the widespread adoption of EV's. A major reason for obtaining use experience in the ERDA EV research and development program with vehicles in the relatively near term is to provide the necessary answers to component reliability questions and uncertainties regarding problems of recharging or battery replacement.

Q. 6. What impact on the program might we expect from:

a) synthetic hydrocarbons and alcohols,

b) synthetic gases, including hydrogen,

c) hybrid systems -- including flywheels, fuel cells, and internal combustion engines?

R. 6a. The availability of synthetic hydrocarbons and alcohols could limit the extent of EV applications. However, in the near term availability of such fuels will be limited and cost will be high (in terms of dollars, manpower, and materials).

b. The availability of synthetic gases, especially hydrogen, could also limit EV applications.

c. Hybrid systems (including flywheels, fuel cells, and internal combustion engines) could have a desirable impact on the EV program. They may be desirable if the EV's are too limited in range and performance. The ERDA EV program is planned to determine which if any hybrid designs are attractive. In the longer term, hybrids will have the same problems as any heat engine prime mover in obtaining conventional fuel.

Q. 7. Is the timescale of the program appropriate? Should phase-1 (conventional chassis) be eliminated or compressed, in view of the current state of the industry?

R. 7. The timescale of the program is not realistic. The proposed schedule does not permit sufficient time to: develop proper specifications to ensure that the best possible test vehicles are acquired; procure the vehicles using standard government procurement requirements; and test the vehicles in realistic use programs after delivery. Also, it does not allow sufficient time in the latter stages of the program to incorporate the systems resulting from the research program into the last vehicle "buy" as well as to incorporate design information generated from the experience obtained from the first "buy". In general we favor eliminating Phase I as currently proposed. The conventional chassis is not appropriate for an EV as noted in earlier testimony.

Q. 8. What about heating and air-conditioning? Is adequate consideration being given to the severe effects of temperature on battery life and performance?

R. 8. Heating and probably air conditioning will be required in the ultimate EV although current state-of-the-art in batteries make this difficult to include in a well performing current EV. Ultimate provisions for these amenities are not considered to be a major technical hurdle. In the planned ERDA R&D program consideration will be given to the effects of temperature on battery life and performance.

Q. 9. What are the special safety problems?

a) Are electric vehicles safer in some respects, so that current vehicle regulations might be relaxed?

b) Are there hazards (as sulfuric acid spills,...) that ought to be specially addressed?

R. 9a. The ERDA defers discussion of this subject. The Department of Transportation has the responsibility for promulgating safety standards. It should be consulted on this subject.

9b. There are special safety hazards associated with EV's which must be addressed. These include possible electrolyte spills and exposed electrical connections, high voltage and amperage, gaseous hydrogen emissions associated with charging operations and differences in mass distribution from conventional vehicles.

Q.10. Is sufficient attention being given to the relation between energy-storage (specifically) for electric vehicle transport, and work on intermittent (solar) and load-leveling large-scale energy-storage of the utilities?

R.10. Yes, but additional analysis is required to better define the relation between energy-storage for electric vehicle transport and for utility load-leveling. The integration of electric-vehicle storage, as well as other types of storage and future electrical loads are undergoing analysis by the Electric Energy Systems Division of ERDA in cooperation with the Electric Power Research Institute, EPRI. The objective of this analysis is to develop appropriate least cost, least energy scenarios for the electric power industry under varying degrees of penetration of all new technologies including electric vehicles. The potential impact of electric vehicles on the utility industry has been estimated (see references 1 & 2) for the year 2000:

i) Number of electric vehicles	1.8×10^7 (or about 10% of total vehicles on road)
ii) Annual production rate of electric vehicles:	5×10^6 (or about 20-25% of total automobile market)
iii) Utilization:	10,000 miles/year
iv) Battery charge:	0.5 KWh/mile (70% Wh efficiency)

The electricity required for charging the electric vehicles is about 9×10^{10} KWh. This would represent only 0.9% of projected total electric energy generated in the year 2000.

Q.11. Looking toward our total energy problem, should we, while substituting electric vehicles for internal combustion vehicles, at the same time, decrease the total energy going into transportation -- in part via a reduction in the total number of individual vehicles?

a) How great an impact would bicycles (electric and non-electric), and carriers (baggage compartments) for them on public transportation -- and small (1-passenger) commuter vehicles have?

R.11 & 11a. A reduction in energy consumption in the Transportation Sector could be a result either of reducing the total number of vehicles, reducing the travel mileage for the total vehicle population, improving operational procedures, improving energy conversion efficiency (improved engines & powertrains, lower performance and reduced vehicle weight, etc.) or through any combination of these. At the present time, we do not have data available on the impacts of bicycles and small commuter vehicles.

Q.12. Certain foreign countries (Germany, Japan, in) seem to be well ahead of us in the design of chassis and certain E-V components. This fact has been viewed as both a threat and an aid (through cooperation) to U.S. E-V technology and production. Which of these views is more nearly correct? What actions should we take in this matter?

R.12. It is not at all clear at the present time whether any one country is ahead in overall EV system technologies. The government of Japan has sponsored an agressive program of battery development with their industry since 1970 and they may be ahead of us in this one area. Similarly, the British government has sponsored battery research for the EV application. U.S. research will be focussed in relatively weak technology areas such as batteries for on-the-road vehicles and can be expected to bring the U.S. to the forefront. We should view the advances made by foreign nations as providing an extra incentive to U.S. industry to work harder to better compete in domestic and world EV markets.

Q.13. What are the basic objectives of technology demonstration programs and what general criteria must be recognized in establishing and planning such programs?

a) Given the above general objectives and criteria, exactly how do they relate to the proposed E-V program?

b) What schedule (time) and size is appropriate for the E-V program? Why? Some of the witnesses suggested one and three years were too short for the two phases of the demonstration program. Given the current state of the technology, what real accomplishments are possible within this time frame?

c) If the program were delayed until advanced batteries were available, what would be the benefits of the program? How would these benefits differ from those of an earlier program? What would be the costs and disadvantages of such a delay?

d) What would be the advantages and drawbacks of having a demonstration program proceeding in parallel to advanced battery development? What time scale is likely and reasonable for each?

e) What are the non-technological benefits of the demonstration program; could they be realized with today's batteries?

f) How, exactly, does current cost-effectiveness relate to the objectives of the demonstration program? How would your response be affected by given future cost increases in petroleum; in cost decreases in electric vehicle component and manufacturing?

R.13. Technology demonstration programs are generally aimed at displaying new technologies in the form of new hardware to industry and the public. The demonstrated hardware can be, in its display form, ready to be precisely duplicated in mass produced versions. In some cases the displayed hardware would be in prototype form. Criteria to be recognized in planning a demonstration program include:

- Feasibility of the technical principles has been successfully proven earlier in hardware tests.
- The new technologies are understood well enough to be exhibited with confidence of public acceptance.
- The expected demonstrations should serve as a catalyst stimulating further technology improvements and ultimate commercialization by others.

13a. The current state of the art in EV's meets each of the criteria noted above. The stated purpose of the proposed legislation is in consonance with the general aim of demonstration programs explained herein.

13b. The EV R&D program proposed by ERDA as described in eralier testimony is felt to be most appropriate.

c,d&e. There are a number of applications where advanced batteries may not be essential while still being very desirable, e.g., postal service vehicles, utility service trucks, delivery trucks, etc. In these cases the very high proportion of idling time gives particularly poor fuel economy with conventional vehicles. The use of EV's in these applications might be unnecessarily delayed by waiting for advanced technology batteries. Also, a great deal needs to be learned about using a vehicle with such different operating characteristics as the EV. This can be accomplished with vehicles using lead-acid batteries.

f. Current cost effectiveness is something that cannot be accurately predicted at the present time because the EV has not been produced in large quantities. However, preliminary analyses indicate that the EV is cost-effective only for very specialized applications. As stated in earlier testimony, the current electric automobile life-cycle cost results in a higher operating cost per mile than a conventional vehicle used for similar purposes. Large scale demonstrations of vehicles with this higher cost could discourage the acceptance of electric vehicles. A petroleum cost increase or an EV cost decrease would of course enhance the value of the experience gained in the demonstration program as these types of vehicles then might see more widespread use.

Q.14. Should H.R. 5470 include, perhaps as an independent phase, hybrid vehicles suitable for longer-distance travel? What type of hybrid systems would benefit from a Government-sponsored demonstration program, and in what time frame?

R.14. Hybrid system development is planned as part of the ERDA Transportation program. There are virtually no hybrid systems on the road today. We believe that continued development and not demonstration is needed at the present time.

Q.15. Should a rental, cooperative or leasing component be included in the program -- in analogy to that of the Witkar in Amsterdam?

R.15. Any proposed legislation with such a demonstration should give the Administrator the option to implement a rental, cooperative or leasing component in the program. Exercise of the option should be based on feedback of information from market surveys, user discussions etc. This is a continuing activity as the program proceeds.

Q.16. Just how severe is the problem of "mix" (E-V's with ICE's) from a safety viewpoint for the demonstration vehicles? Please document your answer.

R.16. Safety considerations were previously addressed in 3f, 9, and 13a above. There is no single good answer to this question. The planned ERDA EV program is aimed at providing data which would contribute to answering this question as well as others.

Q.17. What is the available data for evaluating fuel economy comparisons of the electric car with gasoline powered vehicles?

Q.18. What assumptions are used?

R.17&18. Comparative energy use (BTU/Mi) are shown in Figure 2 for the EV with various I.C. powered vehicles. The EV's shown have the characteristics shown in Figure 3. An average electricity generation efficiency of 36% and distribution efficiency of 92% were assumed for the EV's. The low performance I.C. vehicle shown has the same performance capability as the EV's. This Figure 2 does not reflect the ability of the EV's to use fuels either more available in the future than petroleum-based fuels (e.g., coal) or renewable energy sources (e.g. breeder reactor, fusion, solar energy etc.). Petroleum saved by an EV in 3 cities is shown in Figure 4. This figure assumes certain future characteristics of power generation in these cities (e.g., percent of coal and oil based powerplants, etc.). The assumptions used in developing these figures are detailed in Volume I Executive Summary and Technical Report...Impact of Future Use of Electric Cars in the St. Louis and Philadelphia Regions (EPA 460/3-74-020-A, August, 1975).

Q.19. Please provide quantitative information on the actual inefficiency (energy waste) and pollution produced by urban, passenger vehicles in normal use. How much time is spent idling (at traffic lights, in rush-hour traffic,...) for the typical, urban commuter?

R.19. The road load thermal performance of conventional passenger cars is in the 10 to 15 percent range. The exhaust pollution varies with the use and age. Automobiles in use in most cities are major HC and CO sources. Nearly all carbon monoxide is automotive related. Figure 5 indicates percentages of hydrocarbon from mobile sources in sevaral major cities. For the EPA Urban Driving cycle approximately 18 percent of the time is spent at idle (see figure 6). The fuel consumed at idle is in the order of 6 to 9 percent of the total.

Q.20. In the EPA report cited by Mr. Brogan, the energy efficiency of the lead-acid battery was given as 46% (Table 1.2, Vol. I, p. 3). In attachment D (Research Publication GMR-1798, p. 5) to the testimony presented by GM, the overall charge-discharge efficiency was given as 70%. Please clarify; give all assumptions, calculations and documentation.

R.20. The energy efficiency of a battery may be defined as the ratio of energy removed to energy returned during recharge to the original fully-charged state. It is a function of the rate of discharge and rate of charge and is sometimes expressed as the product of a charge efficiency and a discharge efficiency. Other than rate of charge and discharge some of the more important factors which affect battery efficiency are temperature, degree of overcharge, battery age and history of charge/discharge, battery maintenance, and battery construction and design including for different lifetimes, weights, and costs. Since battery discharge rates are dependent upon the modes of the driving cycle the overall battery energy efficiency can vary with different driving cycles. Also, the battery discharge rate, and thus its efficiency, for a given driving mode is affected by the characteristics of the other components of the electric vehicle system; including motor, transmission and accessory efficiencies, controller cut-off amperage, etc..

The two "battery efficiencies", 46% and 70%, cited in the EPA report (Ref. 3) and the GM publication (Ref. 6), respectively, are on different definitional bases, are both calculated but by different techniques, are essentially for different batteries - one with characteristics determined by experimental data and the other with assumed characteristics considered representative of a projected 1980 capability - and are based on quite different assumptions when considered representative of the battery's efficiency while in the electric vehicle during its negotiation of a driving cycle. The following is a comparison of the most important considerations in development and usage of the two percentages. The circumstances differ greatly.

GM Publication - 70% overall charge-discharge energy efficiency	EPA Report - 46% energy efficiency of battery
• Incorporates 90% efficiency of charger (Thus, battery eff= $\frac{70}{.9}$ = 78% as stated in GM publication).	• Charger efficiency not included.
• The 78% was calculated from experimental voltage and charging data from the battery manufacturer. An 8-hr. charge rate using a charger that varies current linearly with time was assumed. - This efficiency appears closest numerically and definitionally to the charge efficiency as defined and used in the EPA study.	• The 46% is an effective efficiency calculated from the outputs of a computerized model used to produce range and energy consumption estimates. It can be defined as the ratio of (1) energy output of battery during vehicle negotiation of the driving cycle to (2) energy returned to recharge battery to fully charged state - (1) was calculated by computer for each mode of the driving cycle using power density curve (Fig 5.2 in EPA report) and summated repeatedly over the driving cycle to the termination point defined below. - (2) was calculated by reading from the power density curve the energy available (23 wt hr /lb.) at low power level drain and dividing by the charging efficiency (83%) calculated from a typical charge-profile (Fig. 5.4 in EPA report).

IMPORTANT ASSUMPTIONS:

• Difference between efficiency at slow constant discharge rate compared to driving cycle is small.	• No comparable assumption since energy output was calculated for each mode of driving cycle and used in battery efficiency calculation.
• New Battery (Delco Remy 512, lead acid).	• New Battery (lead acid, projected).
• Experimentally determined energy density and power density characteristics.	• Composite Sp. power vs Sp. energy curve between Delco 512 and EV 140 batteries.
• 10% overcharge.	• 7% overcharge.
• Used GMPR suburban & urban driving cycles	• Used SAE Metropolitan Driving Cycle
• Termination of range calculation when available energy (power density curve) at maximum power level required was used.	• Termination of range/energy calculation when $K = \sum \frac{P_B\,dt}{E_A} = 1$; where K is percent battery energy used divided by 100, P_B is power required from battery, dt is time differential at P_B level, and E_A is battery energy available at P_B level.
• Considerable residual energy remains totally available in battery and does not need replacement; thus that the energy output from battery is the same that must be replaced.	• Little residual energy left in the battery after discharge over the driving cycle and thus that the energy to be replaced is equal to that to be replaced at the 20-hr. discharge rate.
•(Other vehicle system efficiencies not pertinent to efficiency calculation, only to energy consumption calculations.)	• Mechanical eff = .9; electrical eff. = .8. These and other parameters incorporated into the model such as drag, rolling resistance, and regenerative braking determine the calculation of battery discharge energy/rate and thus, the resultant efficiency.

It is noted that the 46% figure was not used for any calculations in the EPA report; rather, it was an end result after energy output of the battery was calculated by computer for negotiation of the driving cycle and after total energy required to recharge battery was calculated from a power density curve and charging efficiency. The computerized calculations of range and total energy consumption reasonably agree with experimental values and thus, the purposes of the study were adequately served. The 46% was calculated and tabulated to compare to advanced battery efficiencies. The 70% was used to calculate total energy consumption after the energy output from the battery was determined from the power density curve as that energy available at the maximum power level.

From discussion with the authors of both studies and with other battery experts and from examination of other published data it appears that a practical state-of-the-art battery efficiency in a vehicle operated in the public sector would be somewhere near the mid-range between the 78% and 46%.

Q.21. When the battery technology becomes sufficiently mature, in your point of view, what size demonstration would be desirable?

a) Over what time period?

b) How many manufacturers should be involved and how many vehicles per manufacturer? Please state the basis for your reply.

c) What time would be needed for procurement; for performance evaluation; for evaluation of institutional and societal effects and of consumer acceptance.

d) What funding level would be required?

e) What production capacity would be required for appropriate batteries, electric motors, controllers and other components, chassis and E-V assembly? How do these compare with current capacities in each instance?

R.21a. The time period should be similar to the program schedule described in earlier testimony.

21b. There are currently 21 potential manufacturers. The number of manufacturers to be involved depends in part on their response and willingness to participate. In order to have a manageable program, but with competition between suppliers, the number of manufacturers that should be involved probably is between ten and twenty.

21c. The time period from the point it is known what to procure until the contract is signed would be about 9 months. Road and laboratory performance evaluation not including life-cycle costs, durability nor consumer tests could be completed with comprehensive data analysis and publication of the report within 6 months from delivery of hardware. Instititional and societal effects and consumer acceptance could be evaluated by a six to nine months contract study from the time the contract is initiated.

21d&e. Determination of the required size of demonstration, funding level, and production capacities requires separate detailed study before definitive response can be made.

Q.22.· Please comment on the need to address the establishment of a support infrastructure (mentioned on p. 4 of Dr. David's testimony

R.22. We agree with Dr. David. It takes time to develop this support infrastructure and demonstration might aid in identifying the requirements/problems and in reducing this time. Also, any demonstration program should allow for time to develop an infrastructure in support of the demonstration. This requirement has been considered in the ERDA RD&D schedule.

Q.23. Prof. Thornton mentioned the desirability of a "mini-demonstration" (p. 6) and the need to improve the methodology of battery research. Please comment on these two proposals and the ways in which they might be implemented in H.R. 5470.

R.23. The ERDA schedule position as described earlier is somewhat between that originally contained in H.R. 5470 and Prof. Thornton's recommendation. We believe Thornton does not place sufficient emphasis on the lessons to be learned from actual use experience as discussed previously. Thornton calls for a one month study after the act is passed to come up with an R&D plan. The ERDA research program schedule recognized the desirability of using experts in the field to provide guidance to the program on a continuing basis in the form of a technical advisory committee.

Q.24. What level of support is desirable in H.R. 5470 for battery R&D directed specifically toward improved performance electric vehicles?

R.24. As summarized in Tables 1 and 2, the desirable level of support for battery R&D is estimated to be $60 million for an initial three-year effort and $100 million if the time period were to be extended to five years. Of course, any Federal funding would also be contingent on overall budget considerations in reviewing national priorities.

Ref. #1

TABLE 1

FUNDING LEVEL FOR BATTERY R&D

	Three Year $(x10^6)$	Five Year $(x10^6)$
1. Batteries Total	60	100
Pb/Acid		
a. State-of-the-art	(2)	2
b. Improved	(6)	8
Ni/Zn	(6)	(9)
Advanced; Li/MS, Na/S, Zn/Cl_2, Metal/Air, etc.	(45)	(80)
Test Facility and Standards	(1)	(1)

Ref. #2

TABLE 2

DEVELOPMENT GOALS FOR E.V. BATTERIES

		Pb/Acid		Ni/Zn	Advanced[b]
	Off-the-Shelf (1975)	State-of-the-Art (1978)[a]	Improved (1980)[a]	(1980)[a]	(1980)[a]
Specific energy, Wh/kg[c]	24	33	50	90	80-150
Depth of Discharge, %	80	80-90	80-90	80	60-80
Cycle life	200-300	800	> 500	> 500	>300
Weight of a 25 KWh Battery[d], kg	470	345	230	130	95-190

---

a. Program initiation - Jan. 1976

b. Advanced batteries include Li/MS, Na/S, An/Cl_2, Metal/air, etc.; this is an intering objective.

c. 3-hr discharge rate

d. To prop

Ref. #3

FIGURE 1

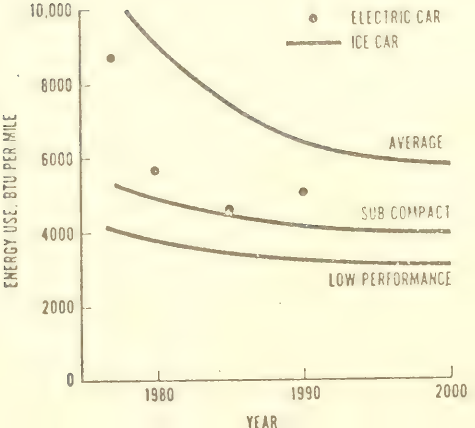
ADDITIONAL ENERGY FOR TEMPERATURE CONTROL

(PERCENT OF BASIC RECHARGE ENERGY)

	ST LOUIS	PHILADELPHIA
SUPPLEMENTAL HEAT		
JANUARY	10 - 13	10 - 13
FULL YEAR	2.4 - 3.1	2.6 - 3.4
PRE-HEAT		
JANUARY	9 - 18	9 - 18
FULL YEAR	3.8 - 6.8	3.8 - 6.8
COOLING		
AUGUST	15 - 20	11 - 14
FULL YEAR	3.4 - 4.4	2.4 - 3.1

FIGURE 2

COMPARATIVE ENERGY USE



Ref. #3

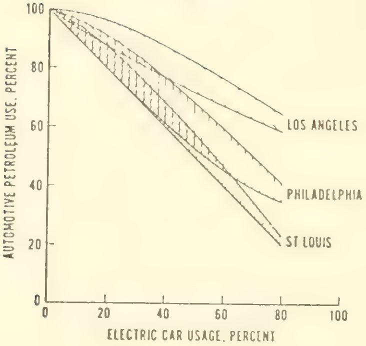
FIGURE 3

ELECTRIC CAR CHARACTERISTICS

BATTERY TYPE	LEAD-ACID	NICKEL-ZINC	ZINC-CHLORIDE	LITHIUM-SULFUR
CAR WEIGHT, LBS	3975	3530	2950	2575
URBAN RANGE, MI	54	144	145	138
BATTERY WEIGHT, LBS	1500	1090	570	300
ENERGY CONSUMPTION, KWH/MI	0.79	0.51	0.41	0.45

FIGURE 4

PETROLEUM SAVING
1990



Ref. #4

Figure 5. Air Quality Benefits - Oxidant (by Air Quality Control Region)

CITY	1970 OX ppm MAX*	PERCENT MOBILE HC**	1975 OX 1-yr DELAY*** ppm*	1975 OX NO DELAY ppm*	OX REDUCTION NO DELAY ppm*
LOS ANGELES	0.67	71	0.501	0.479	0.022
SAN FRANCISCO	0.30	59	0.237	0.229	0.008
SAN DIEGO	0.40	84	0.280	0.265	0.015
SACRAMENTO	0.24	60	0.189	0.182	0.007
HOUSTON	0.324	22	0.296	0.292	0.004
PHOENIX/TUCSON	0.145	60	0.114	0.110	0.004
S. LA. AND SE TEXAS	0.13	24	0.119	0.118	0.001
BOSTON	0.211	44	0.176	0.171	0.005
PHILADELPHIA	NO PROBLEM	--	--	--	--
PORTLAND	0.14	66	0.107	0.103	0.004
FAIRBANKS	NO PROBLEM	--	--	--	--
BALTIMORE	0.26	64	0.201	0.193	0.008
N.Y.C. AREA	0.18	59	0.136	0.130	0.006
SPOKANE	NO PROBLEM	--	--	--	--
DENVER	0.13	66	0.113	0.106	0.007
WASHINGTON, D.C.	0.16	88	0.110	0.103	0.007
PITTSBURGH	0.17	77	0.123	0.117	0.006
SEATTLE	NO PROBLEM	--	--	--	--
MINNEAPOLIS/ST. PAUL	NO PROBLEM	--	--	--	--
SALT LAKE CITY	NO PROBLEM	--	--	--	--

*All concentrations averaged over 1 hr

**Includes heavy duty vehicles

***Federal car program only. No retrofit, transportation strategies, etc, and at end of 1975 production

Figure 6. Descriptions of EPA Urban and Highway Driving Cycles

EPA Urban Driving Cycle

Average Speed - 19.5 mph
Stops per mile - 2.5

	Mode of Operation (1)				
	Accel.	Decel.	Cruise	Idle	Total
% of distance in mode	22	18	60	0	100%
distance in mode (mi)	1.64	1.35	4.47	0	7.46 miles
% of time in mode	23	20	39	18	100%
time in mode (sec)	316	274	535	247	1372 sec.

EPA Highway Driving Cycle

Average Speed - 48.6 mph
Stops per mile - .2

	Mode of Operation (2)				
	Accel.	Decel.	Cruise	Idle	Total
% of distance in mode	13	8	79	0	100%
distance in mode (mi)	1.29	.86	8.08	0	10.2 miles
% of time in mode	15	11	73	1	100%
time in mode (sec)	117	82	560	6	765 sec.

REFERENCES

1. N. P. Yao and J. R. Birk, "Battery Energy Storage for Utility Load Leveling and Electric Vehicles: A Review of Advanced Secondary Batteries", paper to be presented at 10th IECEC, Newark, Delaware, August 18-22, 1975

2. P. A. Nelson et al., "The Need for Development of High-Energy Batteries for Electric Automobiles", ANL-8075, Argonne National Laboratory (November 1974)

3. General Research Corporation, "Impacts of Electric Car Use in St. Louis, Philadelphia, Los Angeles", May 8, 1975. Vol. 1 Executive Summary & Technical Report - Impact of Future Use of Electric Cars in the Los Angeles Region - EPA-460/3-74-020-A, October 1974. [Figures 1-4]

4. "Examination of Issues Related to Two-Car Regional Emission Control Strategies", Aerospace Report, ATR-73(7324)-1, April 30, 1973

5. Research Plan for Reducing Automotive Fuel Consumption", Aerospace Report for National Science Foundation, (draft report, unpublished)

6. General Motors Corporation, "Energy Utilization Comparison of Gasoline and Battery - Electric Powered Urban Vehicles", (GMR-1798) November 15, 1974

I have a couple of announcements I want to make here.

First of all, we're meeting tomorrow morning at 8 a.m. Congressman Brown will be chairing that meeting tomorrow at 8 a.m.

Mr. **Brown**. At 8 a.m.? [Laughter.]

Mr. **McCormack**. Dr. Ed David, vice president of Gould, Inc., which is one of the manufacturers of batteries, will be testifying. Dr. James Braughton, Division of Delivery Services, U.S. Postal Service, accompanied by Mr. Donn Crane, Director of the Office of Fleet Management, Delivery Services Department of the U.S. Postal Service; Mr. Cruse W. Moss, president, AM General, Wayne, Mich.; and Mr. Forbes Crawford, president of Jet Industries, Ltd., of New York will also be testifying.

I would like to also announce that the electric vehicle display will remain available outside until 3 p.m. I don't know the exact schedule, but I presume there will be electric cars on and off in the horseshoe until 3 p.m. today.

I want to thank you all for coming.

We stand adjourned.

[Whereupon, the subcommittee was adjourned at 12:07 p.m., to reconvene at 8 a.m., on Wednesday, June 4, 1975.]

ELECTRIC VEHICLE RESEARCH, DEVELOPMENT, AND DEMONSTRATION ACT OF 1975

WEDNESDAY, JUNE 4, 1975

House of Representatives,
Committee on Science and Technology,
Subcommittee on Energy Research,
Development, and Demonstration,
Washington, D.C.

The subcommittee met, pursuant to adjournment, at 8 a.m., in room 2318, Rayburn House Office Building, Hon. George E. Brown, Jr., presiding.

Mr. Brown. The meeting of the Energy Research, Development, and Demonstration Subcommittee will please come to order at this time.

This is our second day of hearings on the electric vehicle legislation, H.R. 5470.

We are fortunate in having with us this morning a group of witnesses, all of whom are very much involved in the details of the electric vehicle business, either as manufacturers of vehicles or batteries, or as Government procurement officials. I think that this will be a very important part of our exploration of this whole subject.

This morning our first witness is Dr. Edward David, who is well known to the committee by virtue of his former role as Science Adviser to the President. He now is in a position where he can make a substantial contribution toward solving all of the Nation's problems and helping us on the electric vehicle bill. We are very happy to see you, Dr. David. You may proceed with your testimony in whatever fashion is suitable to you. The entire statement that you have prepared will now be included in the record.

STATEMENT OF DR. EDWARD E. DAVID, JR., EXECUTIVE VICE PRESIDENT OF R. & D., GOULD, INC.

[The complete prepared statement of Dr. Edward David is as follows:]

Dr. Edward E. David, Jr., Executive Vice President, Gould Inc.

Mr. Chairman, as Executive Vice President of Research and Development of Gould Inc., manufacturer of industrial, electrical, electronic and battery products, I welcome this opportunity to appear before this Committee to express my views on the Electric Vehicle Research, Development and Demonstration Act of 1975. Gould has experimented with electric vehicles for a number of years, and currently we are manufacturing the electrical propulsion unit for the Postal delivery quarter-ton van which is produced by American Motors General Corporation. In addition, Gould has an on-going research and development program aimed at advancing the state-of-the-art, and I will have more to say about that later.

Let me begin my commentary on H.R. 5470 by saying that I support its objective to demonstrate the commercial feasibility of electric vehicles, and so to accelerate the emergence of a viable industry. The barriers to this development are both technological and economic. I believe that the time is ripe to begin a resolute attack on these barriers, since electric vehicles have the potential for a new dimension in personal transportation. Their properties are distinct from internal combustion vehicles, and this uniqueness promises to make them competitive in many situations.

In one instance, this is already the case. Today, about 50% of all manufactured fork-lift materials handling trucks are electrically driven. They are a major component of the world's 300,000 current electrical vehicles. The other major usage is, of course, in golf carts.

A further expansion of the electrical vehicle's domain seems feasible because of certain fundamental advantages. They emit no pollutants and generate little noise, require little maintenance, have low fuel cost, and are compatible with the long range trend to electrical energy supply in many parts of the country. However, this larger domain for electric vehicles is constrained by their limited performance, high first cost, and lack of a service infrastructure to support them. While some of these constraints would be reduced by the H.R. 5470 program, some are fundamental to the nature of electric propulsion or require massive advances in the state-of-the-art which are not likely in the 3-year time frame of the Bill. This realization implies that the program envisioned under H.R. 5470 should be focussed more specifically on those situations where the unique attributes of electric vehicles make them competitive. Furthermore, the definition of the vehicles considered under the Bill should be expanded. Let me try to be more specific.

At present, electric vehicles can travel nominally 25 to 60 miles at speeds up to 50 mph between battery charges. This limitation is reinforced by the so-called "filling-station" problem. Recharging of the battery requires hours, not minutes as filling a gasoline tank does. Though battery replacement is conceptually feasible in a filling station. That tactic brings some deep implications; for example, battery leasing to the customer and considerable capital investment in chargers, batteries, and handling equipment by the supplier. Widespread availability of such facilities is at least some years in the future. Such limitations imply that the most suitable situations for electric vehicles in the immediate future are delivery service on fixed short routes as illustrated by the electrical postal van, passenger service within self-contained communities such as malls and resort villages, defined center city areas, and shuttle services between near-by fixed points. Gould's studies of the feasible markets for on-road electric vehicles points toward such situations as being the most promising. I believe the demonstration aspect of HR 5470 should be specifically pointed at such opportunities so that the resulting program will not overreach and yield unsatisfactory results. In particular, individual commuter services from suburbs to urban centers is a marginal application at present and in the near future. The demonstration aspects of the Bill should not be hinged to that role for electric vehicles.

However, the Bill can influence a much larger realm including the commuter car if it were specifically to include hybrid electric-internal-combustion vehicles. The Bill as it is now written mentions hybrids, but by implication restricts their participation to instances where "a non-electrical source of power designed to charge batteries or provide auxiliary power to the wheels". We at Gould have studied the hybrid and have a prototype which has many of the advantages of a pure electric, but is much more broadly applicable at the present state of technology.

In this vehicle, the *energy* for travel is provided by a small constant-speed internal-combustion engine, while the *power* for hill-climbing, acceleration, and other demand performance is provided from batteries. The vehicle is also able to be operated as a pure electric over the usual distances. The engine power required is usually less than 20 horsepower and can be provided by a conventional IC engine, or an unconventional source such as a turbine or a linear engine. A hybrid of this kind requires no special infrastructure for support and bypasses the "filling station" problem. Yet it has many of the pure electric's advantages, particularly, low pollution and operating costs, and high fuel efficiency. Hybrids could be considered for such demanding applications as taxi fleets, school buses, and vans for servicing large parts of an urban area. Thus, I recommend that the wording of the Bill be modified to include in the definition of electric vehicles, "a non-electrical source of power designed to energize the electric drive so as to extend the range and performance, attainable by batteries alone".

I recommended also that more emphasis in the Bill be placed upon establishing an infrastructure to support electric vehicles. This should include repair and parts depots, service stations for battery swaps, special customer financing including battery leasing (battery costs can be as much as ¼ to ⅓ of the electric's first cost), and a distributed network of charging stations. Such features are esssentials if the commercial feasibility of electric vehicles are to be demonstrated over the next few years.

Tied into this infrastructure objective is another aspect. Mr. Chairman, I applaud the implicit strategy of the Bill which is to accelerate development of a viable EV industry by using incentives, particularly by creating a substantial market. However, I would like to see that strategy made clearer by insisting that elements of the demonstration program be certified as having a long range market potential. Without this stipulation, the demonstration may become concentrated in applications which are of marginal or no appeal to consumers, and so will be abandoned as soon as government subsidization is removed. The 3-year duration of the program makes this aspect particularly critical to its success.

Finally, Mr. Chairman, let me comment briefly on the future for EV's that this Bill is aimed at developing. I believe the future can be bright principally because of the technological initiatives that have appeared spontaneously in the R & D community in the past few years. Some of this activity is Federally financed, but a large part represents private initiative. This latter part should be carefully preserved—Federal funding should not displace private funding. This is another reason to aim your Bill at creating the investment required outside the R & D area which is necessary for a viable industry, and yet is too speculative to attract funding. With respect to R & D, the bill should be pointed at long range objectives such as exotic batteries and fuel cells. Little or no Federal support is required for short range developments such as Gould's nickel-zinc battery. That battery development is within two years or thereabouts of a successful prototype, which could decrease the weight and volume for a given storage battery by a factor of two-to-three, would have an adequate cycle-life, and would be economically feasible. Furthermore, the raw materials in the battery could be recycled. Needless to say, such a development could have a great impact on the EV market. While nickel-zinc batteries, and other near-in possibilities might be included in the demonstration program, private R & D funding seems to be adequate.

Mr. Chairman, again let me compliment you and your colleagues for bringing this Bill forward and for holding hearings. If we look 20 to 25 years in the future, we can clearly see that new forms of transportable energy will be required if the nation is to maintain a personal transportation system. There are several possibilities, among them synthetic fuels from both fossil and renewable resources including resources from recycling and waste disposal. The other major possibility is in electric propulsion. and I look upon this Bill and the activity it can spawn as a foresighted initiative in the necessary government-industry collaboration toward making electrical propulsion a viable possibility for the future.

BIOGRAPHICAL SKETCH OF DR. EDWARD E. DAVID, JR.

Dr. Edward E. David, Jr. joined Gould, Inc. as executive vice president, Research and Development, in December, 1972. He is also president of Gould Laboratories and a director of the company.

Dr. Edward E. David, Jr., who became Science Adviser to the President, and Director, Office of Science and Technology, in 1970, was born in Wilmington, North Carolina, January 25, 1925. He received a B.S. degree in Electrical Engineering from Georgia Institute of Technology in 1945, and the S.M. and Sc.D. from Massachusetts Institute of Technology in 1947 and 1950, respectively. Prior to coming to Washington in September, 1970, Dr. David was Executive Director, Research Communication Principles Division of Bell Telephone Labs.

Dr. David joined the Bell Laboratories in 1950 and worked subsequently in underwater sound and communication acoustics. From 1963 on he specialized in computing science research, doing research in advanced computing techniques with particular emphasis on "man-machine communication." He has been granted eight patents for his inventions relating to underwater sound, sound localization, and speech processing.

He is the originator of "The Man-Made World." a new course for high school students concerning the principles behind technology. The course was developed to provide "technological literacy" for the general student and was the result of collaboration by teachers, professors, and engineers from industry. The course is now being taught in about 400 high schools. The book received the Operations Research Society of America 1971 Lanchester Prize.

Dr. David was selected by the honorary engineering society, Eta Kappa Nu, as one of the country's outstanding young engineers in 1954. In 1958 he received the George W. McCarty Award from the Georgia Institute of Technology as the outstanding young alumnus of the year. In 1959 he was designated by the Summit, New Jersey Junior Chamber of Commerce as its outstanding young man of the year. In 1971, he received the American Society of Mechanical Engineers President's Award of Merit. The Moore School of University of Pennsylvania awarded Dr. David the Harold Pender Award in 1972. He was the recipient in 1972 of the North Carolina Award, which is the highest award the state can bestow on its citizens.

The author of many technical articles on communication theory, speech hearing, speech recognition and processing, vocoders, and computing, Dr. David is coauthor of two books: "Man's World of Sound" and "Waves and the Ear."

Dr. David is a member of the National Academy of Sciences and the National Academy of Engineering. He is a Fellow of the American Academy of Arts and Sciences, the Acoustical Society of America, the American Association for the Advancement of Science, the Institute of Electrical and Electronics Engineers, and is a member of the Association for Computing Machinery, the Audio Engineering Society, the Engineering Society of Detroit, and the Instrument Society of America.

Prior to joining the government, Dr. David was also Professor of Electrical Engineering at Stevens Institute of Technology and a member of the Board of Directors of the Summit, New Jersey, Speech School.

Dr. David is the recipient of honorary doctorate degrees from Stevens Institute of Technology, The Polytechnic Institute of Brooklyn, University of Michigan, Carnegie-Mellon University, Lehigh University, and the University of Illinois at Chicago Circle.

He was married December 23, 1950, to the former Ann Hirshberg of Atlanta, Georgia. They have one child—a daughter, Nancy.

Dr. David. I will be glad to answer any questions that you may have.

Mr. Brown. Thank you very much, Dr. David. Your statement, although brief, covers the extremely important aspects of this matter in a very cogent way. We appreciate your testimony.

Mr. Ottinger, at this time do you have questions of Dr. David?

Mr. Ottinger. Thank you for your fine testimony. We have been following the Gould's hybrid development with tremendous interest. The bill that I introduced complementary to Mr. McCormack's bill would specifically include hybrids. Mr. McCormack indicated that he is amenable to making the change. I think that this is a development that deserves further exploration.

With regard to the straight electric, I think that there are individual uses with great promise. In the suburbs you have many people using a car for nothing except going to the station from their homes. That seems to be a substantial market. This has not been adequately tapped. It could be through the demonstration with the proper interest. I use a car here just to go from my home to the office and then back home again at night, or to make short trips within the city. I think, beside the uses that you outlined in your testimony, that there is a use for this.

What is the main cost factor in the electric vehicle that keeps it higher, or where is the greatest potential for the cost savings where research could make a difference? Is it in the battery?

Dr. DAVID. The battery is the single largest cost in the propulsion system itself. However, the electric control is also an expensive part of the vehicle. There is potential for cost savings in both. I should point out that in the current lead-acid battery, 60 to 70 percent of the cost is in raw materials, namely lead or lead oxide and the container.

In order to reduce the cost of the battery, you have to "get the lead out." This is a trick that lead-acid engineers and scientists have worked on over the years. They have had only limited success. However, there are some new research leads that look promising.

More immediately the cost of the control in the pure electric vehicle can be reduced by a considerable factor through clever engineering.

Mr. OTTINGER. The most promising alternative to the lead-acid battery that you are working on is the nickel-zinc one.

Dr. DAVID. Yes; you can find a wide variety of opinions as to which is the most promising alternative. We like nickel-zinc because we can see our way clear to producing a prototype with adequate cycle life. I might point out that new batteries appear very seldom on the scene. If you look back over the past 15 or 20 years, only a few new batteries have come into use. Two of these are nickel-cadmium batteries and silver-zinc batteries. The third leg of the stool is the nickel-zinc battery.

Mr. OTTINGER. Would the nickel-zinc battery allow a lighter battery?

Dr. DAVID. We estimate a reduction of a factor of 2 to 3 in weight and size over the lead-acid battery.

Mr. OTTINGER. That is exciting. You think that you will have those in 2 years?

Dr. DAVID. We expect a prototype that is economically feasible by that time; yes. Getting production on stream will take some time longer. We have to arrange also for the recycling of the batteries, which is an important part of the economics.

Mr. OTTINGER. Thank you. I have no further questions at this time.

Mr. BROWN. Mr. Thornton.

Mr. THORNTON. Thank you. I have just a couple of questions.

I would assume, that in the hybrid vehicle, the control mechanism is quite a bit more complicated than in a straight electric vehicle. Is that correct?

Dr. DAVID. It need not be that much more complicated in my opinion, but the question is a good one. I would like to reserve the answer until we do more engineering to clarify the situation.

Mr. THORNTON. I would very much appreciate having an answer to that. At first, it would seem the problem of recharging a series of batteries and drawing on them for excess power, that this might complicate the controls to some extent. I would be very interested to know how you can approach that, Dr. David.

Dr. DAVID. I will write a description of it. However, I believe that the controls will come out to be about the same complexity as pure electric.

Mr. THORNTON. It seems that this is really the electric vehicle which is on the threshold as far as mixing with conventional traffic patterns. Is this your impression, or can a pure electric vehicle mix with conventional traffic patterns?

Dr. DAVID. I would not like to see us put pure electric vehicles on expressways at present. It is probably not really feasible, nor safe to do so, unless a special lane were reserved for them.

However, I do think that the hybrid has the potential to be a general purpose vehicle, whereas, sir, at present, the pure electric does not.

Mr. OTTINGER. Will you yield?

Mr. THORNTON. Yes.

Mr. OTTINGER. Do you have a hybrid vehicle with you, Dr. David?

Dr. DAVID. No; we have built our hybrid vehicle on the Postal Service delivery van chassis. It is in Cleveland. We did not bring it here.

Mr. OTTINGER. Thank you.

Mr. THORNTON. I am aware of a hybrid vehicle used for a considerable length of time in another mode of transportation. Some people may remember the prenuclear times when there were hybrid submarines. The problem with the battery powered propulsion was a significant problem for many years in that field.

Dr. DAVID. That happens to be an area of specialization that I have worked in, and it stimulated my interest in the hybrid vehicle. I believe that the various kinds of propulsion system demonstrated over the years for submarines and other special vehicles, are almost directly applicable to the automobile. The question is, what advantages do they have over the internal combustion vehicles?

Mr. THORNTON. Thank you very much. I have no further questions.

Mr. BROWN. Going back to your testimony, Dr. David, to your nickel-zinc battery, the batteries are, of course, at the heart of our problem here. You mention or suggest that you could have a prototype within 2 years, then a production line model somewhat later.

Invariably, when we talked to the automobile industry, we found that the problems of gearing up for mass production as to a level of numbers, that this seems to be the most time-consuming part of the operation, whether this is for a new engine or almost anything.

I would like to ask you at this time to be a little more precise about the time that is involved in moving from the successful prototype in 2 years to a production line production of the nickel-zinc battery, so, that if everything goes well, and we have a reasonably good size market for it; then how long would it take for you to supply a market for, say, $50,000 units per year?

Dr. DAVID. Mr. Brown, 50,000 units per year is not so frightening; 500,000 or 5 million would be much more demanding. I think in terms of 50,000 per year, one could put that size production on stream within 18 months to 2 years after the prototype was certified and tested.

Mr. BROWN. You indicated somewhere, I believe, that you think a reasonable life, I guess for the nickel-zinc battery, would be in the order of 2,000 charge cycle over a 5-year period. This is, I think, for the Postal Service vehicles. There is a discrepancy here then between the ERDA estimates of 2 years at 600 charge cycle life that they anticipate in the near future. This is for the lead-acid zinc battery. Are we talking about the same situation here? Is there a basic discrepancy in your estimates as compared with ERDA's estimates as to the potential of the batteries?

Dr. David. I have not seen the ERDA estimates. I am not familiar with the logic behind them or the information that is behind them.

However, sir, it seems that those estimates can be reconciled. Our current batteries for the golf carts operate for about 300 charge or discharge cycles. They are a special battery which are designed for that particular application.

An industrial-quality battery, which is the sort of battery that we are installing in the American Motors General postal vehicle, should have a life of around 4 years. As a matter of fact, I believe in the contract, sir, that we had to guarantee this life. We would expect it to go for around 750 cycles. The difference is in the design of the battery.

Mr. Brown. So far, you have not had enough experience with the Postal Service vehicles to know if they meet the life expectancy in actual practice.

Dr. David. No; but we regularly design and construct industrial batteries with at least that lifetime. We have been building such batteries for many years. I would not expect any difficulty, Mr. Brown.

Mr. Brown. There is another aspect of the battery, a characteristic, namely, Dr. David, the cost. In the study done on the applicability of electric vehicles to southern California, which has been noted before, one of the most comprehensive studies of electric vehicles, the life cycle cost for the electric vehicle—well, say in the case of the lead-acid battery, are highly skewed by the range of battery cost. They list a range of 3.5 cents per mile to 9.2 cents per mile as the range of estimated cost just for the battery.

Of course, adding all of the other factors used to estimate the life cycle cost in the study, this brings the electric car with a lead-acid battery up to the highest life cycle cost of any electric vehicle, and considerably higher than the internal combustion vehicle. Can you answer the question as to why should there be a range of 3.5 to 9.2 cents per mile attributed strictly to the depreciation of the lead-acid battery, Dr. David?

Dr. David. I suspect that this variance has to do with this same question as to what variety lead-acid battery we are discussing. Golf cart batteries, are a good deal less expensive than an industrial-style battery which is designed for a longer life. They have been optimized to reduce first cost rather than life cycle cost.

In the industrial application or the electric vehicle application, one would presumably design for the minimum life cycle cost. I suspect that the difference in the figures reflects the difference in the philosophy of design that is reflected in the cost of the materials and the labor to put the battery together.

Mr. Brown. Regarding a battery that is designed specifically for industrial use or electric car use, what characteristics would differentiate it from the present battery? Would it be heavier, bigger in size? How would the design be altered, Dr. David?

Dr. David. It would have heavier plates and they would last longer. They would take a charge more uniformly than the thinner plates which go into a golf-cart battery. The battery that we are putting in the American Motors General van is about one-third as big as this table. It is packaged as a unit. The design is carefully optimized to reduce the heating to which the battery is subjected. The problem of overheating is one of the most important in the design of a long-life battery.

Mr. Brown. In this study, the next most expensive battery is listed as the nickel-zinc, the one that you are holding out such high promise for. I cannot quite understand why the estimates here, which are listed as 5.1 cents per mile for the battery depreciation, would be so much higher than the zinc-air or the other two? They have a very small depreciation figure; yet, we know the least about these batteries. Could you comment on these estimates also? I presume that you are fairly well familiar with the depreciation cost on the nickel-zinc battery. How accurate are these particular estimates, Dr. David, particularly when we are dealing with something that we do not have production models on or much experience with at this time?

Dr. David. The skepticism indicated in your question is well placed. We are very close to the prototype stage for the nickel-zinc battery. We have a relatively firm handle on the cost. We believe that the cost of that battery per kilowatt-hour stored will be just about the same as a lead-acid battery.

As I said, we believe that is a fairly firm estimate. Included in that is the credit for recycling the battery materials.

With respect to the zinc-air and the lithium-sulphur batteries, Gould has been involved in both of those programs. We have looked at their costs rather carefully. The currently quoted costs are targets rather than firm estimates. We don't think that the targets are necessarily realistic. I believe they are speculative. There are many problems in both batteries that have not as yet been solved. The costs, particularly for mass manufacturing of those batteries, have not been carefully determined.

Mr. Brown. Thank you very much.

Let me ask our other two members that have come in if they have questions.

Mr. Fuqua. I have no questions.

Mr. Brown. Mr. Hechler.

Mr. Hechler. I have no questions at this time. Thank you.

Mr. Brown. Will you have some later?

Mr. Hechler. I may have some later.

Mr. Brown. Now, Dr. David, I wanted to ask you some additional questions, but we may have a time problem here this morning with the Subcommittee. I expect, or express the hope, that we could submit some questions in writing to you and you might be able to respond to them at a later time.

Dr. David. I would be glad to.

Mr. Brown. Thank you very much, Dr. David, for your testimony.

Dr. David. Thank you, Mr. Chairman.

[Answers to additional questions submitted to Dr. David follow:]

EV's - ISSUES AND QUESTIONS

GOULD RESPONSE

1. The critical Federal role in aiding the electric vehicle industry is to demonstrate the existence of a market. With current and foreseeable EV technology, the first cost of EV's will be higher than ICE vehicles. So market acceptance must be based upon lower life-cycle costs for EV's. The principal role for a Federal program is to demonstrate EV life-cycle cost advantages.

   The demonstration should focus on applications where there is opportunity for long-range market potential; namely, where requirements on speed , acceleration, and range are well within the current state-of-the-art.

   Some examples of viable EV demonstration applications would be:

   - Delivery service on fixed routes.
   - Passenger service within self-contained areas, such as malls, airports, resort villages, military and other government complexes, and center city shuttles.

   I strongly recommend that any demonstration program must recognize today's inherent EV performance limitations, and carefully avoid placing EV's in applications where their performance will prove marginal.

Along with market demonstration, certain R & D funding is an appropriate Federal role. This funding should concentrate on long-range objectives such as exotic batteries, fuel cells, and advanced control systems such as DC/AC Control systems. Existing electrical and vehicle technologies are, in my opinion, adequate today to permit the development, design and manufacturing of viable electric vehicles for many limited applications as listed above. Federal funding of near-term development itself would be unwarranted. Creating a market for current vehicles is the preferred Federal role.

A further Federal role should be to encourage investment in a speculative industry that as yet cannot attract private funding. The infrastructure required includes: repair and parts depots, service stations for battery swap, customer financing and battery leasing plans, and a distributed network of charging stations. These features should be factored into the demonstration portion of the Federal program such that infrastructure requirements can be demonstrated and analyzed as part of a total transportation system.

2. In my view, a demonstration program, and procurement of EV's themselves must be based upon technological merits. Should low-capital companies display unique technological merit, they should be encouraged to team with other companies, who recognize such marketable technological merit, and would, therefore, be willing

and capable of supplying the required capital. Special consideration of a company's small size or limited resources should be carefully constrained lest technological merit be compromised and the demonstration fail.

Too large a number of firms placing EV's in service during a demonstration program would fragment EV fleets, with a proliferation of dissimilar components, lack of service, and operational uniformity. This lack of component, service and operational uniformity would increase the total cost of creating and maintaining EV fleets, would delay compilation of life-cycle cost data on a comparable basis and would detract from market acceptance.

3. EV maintenance facility requirements differ by type of EV use:

   . Fleet Use: Distributed maintenance facilities are not necessary for EV's used in fleets. Most fleets use fixed-base operation, which can be the facility for maintenance and repair. Thus, the requirement here is for centralized maintenance, service training, and parts support.

   . Consumer Use: Adequate infrastructure, including distributed service facilities for EV's used by consumers as "second" or "third" cars, is a central requirement. The consumer must be assured of a local service capability before he will make an investment in an EV. Thus, maintenance facilities are a major requirement in the widespread consumer use of EV's.

4. I do not anticipate EV use in the foreseeable future being significant enough to require additional electrical generating capacity. There is always the possibility that if there were a large concentration of EV's in one section of a city (at a depot, say), and if all were charged during peak demand periods, capacity problems could result, but that seems quite unlikely.

5. The time scale for Phase I is appropriate if conventional chassis are used with lead-acid battery systems in commercial delivery vehicle types. On the other hand, I do not believe it is feasible to demonstrate an adequate passenger vehicle within the Phase I time frame.

With respect to Phase II, I do not believe that the required massive advances in the state-of-the-art, especially in batteries and advanced control systems, can be accomplished within the three-year time frame of the Bill. This opinion implies that the program should be focused more specifically on those vehicle applications where the unique attributes of EV's make their performance compatible with the vehicle duty cycle (see response to Question No. 1).

6. Today, heating an EV is accomplished with gas heaters. As new, higher energy density batteries become available, heating may be accomplished by electrical means. Air conditioning requires greater energy and will be a problem to factor into EV designs without seriously effecting vehicle range.

The effects of temperature on battery life and performance are taken into account in many EV designs today. A properly designed lead-acid battery vehicle, fully charged and properly maintained, does not suffer from high ambient atmospheric temperatures in either life or performance. Low ambient atmospheric temperatures clearly impact performance but can be compensated by battery heaters and/or storing the EV in a heated garage.

The new batteries under development must consider the temperature problem as their designs evolve. The testing of new batteries must take into account operating temperature ranges.

7. There are a few special safety problems inherent in EV's. Certainly their current low top-speed is a concern, and freeway use may well be hazardous. However, lower speed has some positive benefits. For example, because EV's are top-speed limited by design, high-speed tire regulations could be relaxed to permit the tire industry to design tires with less rolling-resistance.

Certainly, the electrical hazard and potential acid spills are serious design concerns. Competent electrical design can minimize the electrical hazard, and acid spills, although corrosive, are not violently combustible like gasoline and their corrosive effect can be minimized by water flush.

8. In my opinion, the use of EV's for long-distance transport is not feasible in the immediate or mid-range future. Certainly the EV/train/EV sequence has merit, but because of the large investment required is probably a possibility only after wide-spread EV usage on a local basis is demonstrated.

    a. Electrified roadway or guideway concepts are interesting, but again I feel the investment is so great and the system so complex and underdeveloped at the present time, that they should not be part of current EV federal programs.

    b. The Federal role in mass transit is currently being addressed elsewhere and, in my opinion, should not be included in the contemplated EV program. Mass transit issues would needlessly complicate and lengthen an EV development program.

    c. The fuel cell is a promising device for the future. Since input to the fuel cell is based upon petroleum fuels, not energy from the electrical grid, I am not certain what the net petroleum fuel gain will be, if any. The fuel cell promises high energy efficiency but has not yet been proven in vehicle applications and its possible role in EV's is unclear. It conceivably could be an important component in the hybrid vehicle.

9. The basic objectives of a technology demonstration program should be operational and economic feasibility, and long-range marketability. In addition, such programs must be coupled to the marketplace through commercial ventures who are willing and capable of investing in R & D and manufacturing, and are committed to bringing the new technology to the marketplace.

   a. The proposed EV program must be structured to place EV's in applications where real short and long-term market opportunities exist, by companies committed and capable of successfully taking EV's to market if the demonstration program is successful.

   b. Please refer to my response to Question No. 5.

   c. Although we are some five to ten years away from the commercial availability of new batteries, a delay of the EV demonstration program would result in delaying the definition and development of new EV applications, markets and EV life-cycle cost data. An early program has the additional advantage of pin-pointing technical and operational problems which can then be attacked by further R & D.

   d. An early EV demonstration program is attractive only if the applications chosen for EV's recognize their inherent limitations and are consistent with current EV performance. If too ambitious, the total EV program could be discredited before new batteries become available.

e. The major non-technological benefit of the demonstration program is the definition of new EV applications and markets, and the collection of hard performance and life-cycle data on EV's. These benefits can be realized with today's batteries.

f. Cost-effectiveness demonstration of EV's should be the central objective of the demonstration program. Life-cycle EV costing, rather than first cost, must be proven. As petroleum cost rises, it seems likely that the cost advantage of EV's will grow, depending upon the cost trend of electricity. The latter is also tied in part to fossil fuel costs.

10. H.R. 5470 should include provisions to develop and demonstrate the hybrid vehicle. The hybrid is attractive if viewed as a vehicle for longer range travel than the all-electric. However, the hybrid system has not been worked enough to understand its operation and economics; more development and demonstration is needed. Limited demonstrations of various hybrid designs would be useful in evaluating hybrid fuel savings over ICE vehicles, first-costs, life-cycle costs, maintenance costs, and potential market applications and acceptability. Of course, demonstrations would also be useful in encouraging new technology and in clearing up engineering and design problems.

11. A rental or leasing program, similar to Witkar in Amsterdam, is not appropriate for this demonstration program. The investment and operating problems would be too great and might cloud the real issues of EV usage. On the other hand, the program should include rental and/or leasing incentives to accelerate the applications of EV's in fleet operations. For example, the Federal role could be designed to provide EV's on a rental basis to responsible fleet users. Discounts might be provided in return for operating data. Further, battery leasing programs could be used to reduce EV first cost. Rental and leasing provisions are an important aspect of the required service infrastructure and could conceivably be expanded to create service stations for battery swaps. Again, Federal EV funding can, in my opinion, be most effectively used in those areas which are too speculative to attract private investment.

12. A properly designed EV based upon current state-of-the-art technology, demonstrated in the proper application which clearly recognizes EV performance limitations, presents no safety hazards when "mixed" with ICE vehicles on city streets and rural roads. On the other hand, I am concerned about the passenger vehicle application and the implied freeway driving requirement of passenger cars. If freeway driving is required, special lanes should be reserved for EV's.

13. I am unable to locate requested quantitative data on the inefficiency and pollution produced by urban passenger vehicles. Recent vehicle usage studies surveyed do not present hard data in this area and gross estimates based on various driving cycles, vehicle types and traffic patterns is of limited value.

14. A great reservoir of hybrid submarine system knowledge exists in private firms and government agencies. Information on clutching and declutching, alternate power supplies and methods of gearing are documented and well known. In fact, Gould's hybrid vehicle program makes use of past experience with hybrid submarine systems. This knowledge could help compress the time frame required to develop and evaluate hybrid vehicle systems. H.R. 5470 should be modified to include hybrid vehicle evaluation as described in my response to Question No. 10.

E. E. David, Jr.
Executive Vice President
Research, Development and Planning
Gould Inc.

EED/jh

Mr. Brown. Our next witness is Mr. James R. Braughton, Director of the Division of Delivery Services, U.S. Postal Service. He is accompanied this morning by Mr. Donn Crane, Director of the Office of Fleet Management, U.S. Postal Service.

Could you gentlemen please approach the table? You have the unique situation of probably having had more practical experience with electric vehicles and their use than any of our other witnesses. Therefore, you will have a special contribution to make here this morning. We welcome you here and look forward to your testimony.

The full text of your statement may be included in the record at this time. You may read your statement.

STATEMENT OF JAMES R. BRAUGHTON, DIRECTOR, DELIVERY SERVICES DEPARTMENT, U.S. POSTAL SERVICE; ACCOMPANIED BY MR. DONN CRANE, DIRECTOR, OFFICE OF FLEET MANAGEMENT, U.S. POSTAL SERVICE

[The complete prepared statement of James R. Braughton is as follows:]

Statement of James R. Braughton, Director, Delivery Services Department, U.S. Postal Service

Mr. Chairman, we appreciate the opportunity to testify on H.R. 5470 and to describe for you the program we have started in order to introduce energy-saving electric vehicles into the Postal Service vehicle fleet. With me at the table today is Donn Crane, who is Director of our Office of Fleet Management.

H.R. 5470 is a bill which would authorize a Federal program of research, development, and demonstration designed to promote electric vehicle technologies and to demonstrate the commercial feasibility of electric vehicles. This program would be coordinated in the Energy Research and Development Administration (ERDA).

Section 8(a) would require the Postal Service and other agencies to introduce electric vehicles into their fleets as soon as possible. The competitive position of electric models for procurement purposes would be required to reflect life-cycle costing and emission performance. Where the Postal Service or any other Federal agency determined that electric vehicles would be practical from a general performance standpoint but would not be economically competitive with conventional vehicles, the ERDA Administrator would be authorized to pay the increment necessary to make the electric vehicles fully competitive, as part of a demonstration program provided for under section 7.

In recent years, the Postal Service has undertaken a number of experimental projects to develop energy-saving alternatives to conventional vehicles. In April of 1974, we entered into a procurement through the General Services Administration for a total of 352 light delivery electric vehicles, produced by the AM General Corporation. These vehicles generally are counterparts of our ¼-ton light delivery internal-combustion jeep-type vehicles, which presently cost about $2,800 each, compared to the approximately $5,700 paid for each of the electric vehicles. We are now about to begin field operational testing, primarily in the southern California area, as the first deliveries under the contract become available.

Provided that the first 352 vehicles are successful from a cost and performance standpoint, we have additional plans to procure perhaps 1000 more electric vehicles late in fiscal year 1976. In all, we presently have approximately 65,000 ¼-ton light delivery vehicles in our fleet. We are in the midst of a long term procurement contract with AM General for conventional gasoline-fueled vehicles. That contract provides for options to purchase additional vehicles should the requirement exist. We will then be able to determine whether we should order additional gasoline vehicles or should purchase electric-powered trucks instead.

Late in Fiscal Year 1977, we will be facing another large scale procurement. At that time we will have sufficient cost data to determine how much of that purchase should be in electric vehicles. We have sufficient routes suitable to electric vehicle use to enable us to employ more of such vehicles should their use prove economically feasible.

Sufficient supportable comparative data with respect to life-cycle costs were not available to enable us to take those considerations into account in procuring the electric vehicles we are now receiving. However, we are hopeful that our experience with these new vehicles within six or seven months after they are placed into operation will permit reasonable projections of life-cycle costs at the time of our next planned electric vehicle procurement in late FY 1976. Such estimates should enable us to have a better view of the comparative total economic costs of electric and conventional vehicles than is provided by comparing their initial purchase prices. We are confident that electric vehicles will be shown to permit significant energy savings and believe that they are potentially good economic investments when used under appropriate conditions.

If Congress determines that funds should be made available for this purpose, we also would be pleased to work with ERDA to increase the number of electric vehicles used in the Postal Service and would welcome ERDA funding to the extent that electric vehicles that would meet our needs cannot yet be shown to be economically competitive with conventional vehicles.

In the next few months we will have significant cost and operational data developed regarding electric vehicles and we, of course, would be pleased to make our data available to ERDA or any other interested Agency.

This concludes the prepared statement and we will be happy to respond to any questions you may have.

Mr. BRAUGHTON. I would like to add that we have about 112,000 vehicles. Over half of these are what we would classify as our small light delivery vehicles. In the future, our need for vehicles in new areas where we will expand delivery will require motorization. It will require a stop and go situation or a vehicle that will travel a relatively short distance but is required to make hundreds of stops per day.

We, in the Postal Service, sir, share your concern for the development of alternatives to the gasoline-powered vehicles to alleviate the problem of pollution and to conserve energy, Mr. Chairman.

Now, for approximately the past year, we have been operating 31 leased British vehicles in California. Since that time, we have had more than 12,000 vehicle days of service. Our records show that on only 14 vehicle days were they out of service. This is a very good record. The yearly operating cost per vehicle in the experiment computes to only $384.80 per vehicle per year. The city in California I refer to is called Cupertino. This, sir, is significantly below the operating cost of our conventional vehicles. That is the actual operating cost.

Now, about $123 of this was because of necessary body repair. That should not be necessary in future procurements. While this is an expensive vehicle, the one that we are leasing, it has not yet proved to be cost effective. The significant drop in operating cost from our conventional vehicle is quite encouraging. We expect to have a more favorable return on the electrics that are under procurement. I am happy to respond to any questions that you may have at this time.

Thank you, Mr. Chairman.

Mr. BROWN. Thank you very much. I think that the Postal Service is to be commended for recognizing the special characteristics of the electric vehicles that make them suitable for your use. That is the stop and go characteristics of the route delivery.

Mr. BRAUGHTON. Thank you.

Mr. **Brown**. In my own area, the special problems of air pollution exist. I do want to commend you at this time for your efforts in placing some of those vehicles in my own congressional district. It should be very helpful. Perhaps you could select a few more members of the committee to similarly honor, I am sure that they would appreciate it, Mr. Braughton.

Actually, as you are aware, there is the distinct possibility that, under emergency conditions in southern California, all internal combustion vehicles might be prohibited. You would be in the enviable position to deliver the mail while everything else came to a halt.

Mr. **Braughton**. In that area, we are probably 90 to 95 percent motorized. That could create a considerable problem for us if this happened. This application of electrics, sir, in the Postal Service is somewhat unique. We have well-defined routes. We have well-defined characteristics. We could pick and choose where we put the vehicles. We, obviously, avoid the high-speed highways. We have the luxury, I guess, of being able to predetermine where it is that we should put the vehicles before we put them on the street. In this regard, we are somewhat unique. Also, Mr. Chairman, the range in most of our vehicles is quite small. In California, we are averaging a little over 11 miles a day usage.

Now, the range in these particular areas is not a problem, as such.

Mr. **Hechler**. Could you spell out a little more specifically where the electric-powered vehicles—the British type that you are using and the 352 that you also plan to put into service—will be utilized? Are these primarily in urban in-city delivery areas, or do they transport junk mail back and forth?

Mr. **Braughton**. Mr. Crane will respond.

Mr. **Hechler**. Mr. Crane.

Mr. **Crane**. The 30 British vehicles are all concentrated in Cupertino, California, which is below San Francisco. The 352 will be primarily based in southern California. About 300 will be in the San Bernardino, Riverside, Los Angeles basin area. The other 50 or so will be scattered from Charleston, S.C., Evansville, Ind., Cherry Hill, N.J., and there will be 10 of them on northern Virginia at the Merrifield plant. One is here in town.

Now, maintenance programs have begun on that. Of the other 10, 5 of them are located at Hartford, Conn., and the other 5 at New Haven.

Mr. **Hechler**. That does not tell me the kind of service it is.

Mr. **Crane**. Daily delivery service, first-class mail, Mr. Hechler, or anything that actually comes to your particular home, sir.

Mr. **Hechler**. You find that the range is insufficient, say, for using them on any rural routes?

Mr. **Crane**. We had not intended to use them in the rural service. These are all city delivery routes. Probably they would not exceed 15 miles per day. The specification required that the vehicle go for 300 starts and stops and travel 20 miles. It has far exceeded that.

Mr. **Hechler**. And that would include the possibility of going into the suburbs, although southern California is one big suburb.

Mr. CRANE. Yes. But the vehicles are based fairly close to the delivery area. If they are in the surburbs, sir, there is a carrier station in that suburban area from which they come generally.

Mr. HECHLER. On page 3 at the top of the first full paragraph, the middle of the page, you mentioned, and I quote:

> We will then be able to determine whether we should order additional gasoline vehicles or should purchase electric-powered trucks instead.

Mr. BRAUGHTON. Yes.

Mr. HECHLER. You mean the jeep style?

Mr. CRANE. Yes. We consider the jeep as a truck, as a light truck.

Mr. BRAUGHTON. One reason that we don't consider the 352 for any other service is that its capacity is the same, really, as our present light delivery vehicles, the quarter-ton jeep. It would not have the cubic capacity to carry bulk mail between post offices. It is basically designed as a carrier delivery vehicle.

Now, while it would be operating in what we would normally classify as suburban areas, the perimeters of Los Angeles or Hartford, well, this would be on a carrier delivery route, sir, expressly for that purpose.

Mr. HECHLER. Have you had discussions with the AM General Corp. as to whether the $5,700 unit cost is likely to come down in years to come as you make, possibly, extensive purchases?

Mr. CRANE. We have had no discussions in that particular vein. I don't anticipate a great reduction in the price. The cost of all vehicles, including the internal combustion engine vehicles, has risen drastically in the last year and a half. I believe that under significant production numbers, that the potential for lowered or a lower cost is certainly there, Mr. Chairman.

Mr. HECHLER. How do you quantify a figure on lower emissions and air pollution in assessing the relative value of the electric vehicles as against a gasoline-powered vehicle, Mr. Crane?

Mr. CRANE. We do not quantify it. We believe that there is a social value at present which is intangible in terms of dollars and cents.

Mr. HECHLER. Do you go to ERDA, say, under the terms of this bill, when you are trying to establish the amount of subsidy? What figure do you put on the social value of the lower air emissions?

Mr. CRANE. I cannot respond to that. I would like to know what value we could put on this. It would make it easier to justify the vehicle on a cost-effective basis. We made no attempt to justify the vehicle on a cost-effective basis. We justified the 352 vehicle procurement program primarily on the basis of air quality.

Secondarily, we did it on the saving of energy.

Mr. HECHLER. You have $2,900 per unit difference. I think at some time that somebody will have to put a dollar value here, that is, if there is going to be an adjustment in ERDA's relationship.

Mr. CRANE. This is true. I believe it is premature to come up with life cycle costs now. From every indication that we have from the operation of the British vehicles in California and the pilot model of the AM General-Gould model, the operating costs appear to be much less than the internal combustion engine. Over the span of years, we look for a break-even point where electrics will be competitive, provided we extend their life beyond the planned life of the gasoline vehicle, Mr. Hechler.

Mr. Hechler. Since you mentioned the magic word competitive, was AM General a competitive bid?

Mr. Crane. Yes. There were two other bidders.

Mr. Hechler. Were they substantially above $5,700?.

Mr. Crane. Yes. The next bid was $600 more or higher per unit than AM General. Above that was another $600. There was a $1200 spread per vehicle between the three bids.

Mr. Hechler. You mentioned the possibility that, late in fiscal 1977 you will be facing another large-scale procurement. There is the assumption that this will be a procurement from AM General. What about that?

Mr. Crane. We make no assumptions as to who will be the manufacturer that will be successful on the bids. We always buy competitively. We send the bid out to GSA for solicitation and whoever is the successful bidder, that is whom we welcome at the time.

Mr. Hechler. I commend the Postal Service for its initiative in making these tests. This is very useful. Thank you very much.

Mr. Brown. Mr. Fuqua.

Mr. Fuqua. Thank you, Mr. Chairman.

Let me also join in complimenting you. I was interested in Mr. Hechler's comments about your fleet delivery. I assume that it is fleet-footed and fast. I do commend you at this time for being out in the forefront in recognizing the potential of electric powered vehicles.

I think that I was interested in the discussion with Mr. Hechler that, even though the initial cost was considerably higher than the conventional vehicles, that you felt the run-out time would equalize out. You think that when you get more experience with your second generation vehicles or second procurement vehicles, say, by having a larger fleet, that you will be able to get more accurate information about the operational cost.

Mr. Braughton. I think that we will have good operational data available within a few months after installation. I think the thing that, or the question, sir, is the life cycle. There are a lot of discussions about what the life cycle will be. I think that we need more information on this.

Mr. Fuqua. How about your maintenance?

Mr. Braughton. The maintenance is extremely low on the 31 vehicles.

Mr. Fuqua. Are you sharing this information with GSA, Mr. Crane?

Mr. Crane. Yes. We have been in contact with all Federal agencies on the electric vehicle program.

Mr. Fuqua. Have they indicated any interest in this, Mr. Crane?

Mr. Crane. Yes. The head of their fleet operations, Mr. Rhoades, has been in contact with me regularly on the electric vehicles. They are interested in procuring a few for their own purposes.

Mr. Ottinger. Will you yield?

Mr. Fuqua. Yes.

Mr. Brown. Mr. Ottinger.

Mr. Ottinger. Thank you. I would also like to congratulate the Postal Service and these gentlemen with whom we have had contact for their initiative to promote the electric vehicles.

Are you in a position at this juncture to support or not support H.R. 5470?

Mr. Braughton. I don't believe that we are in that position now. The bill really goes beyond our experience.

As I mentioned earlier, we are in a very limited, well-defined area. The bill itself is directed more toward the private use.

Mr. Ottinger. I do not know to what extent the Postal Service is still considered part of the Government, but we do provide for paying financial costs for the Government procurement, that is, between the commercial cost and any differential cost for the electric vehicles. I am interested to know if this bill goes through, whether you would feel able to move away from competitive bidding under the bill and attempt to test a variety of vehicles. You have a certain limitation. If you go out on competitive bids, you have to take the low bidder for the entire quantity of your order.

Under this bill, we hope and look toward your cooperation in being able to get performance testing, Mr. Braughton.

Mr. Braughton. On the competitive aspects, we do not use conventional vehicles. We do have some special requirements that are necessary for a delivery vehicle. We need a specific capacity to handle the mail. All vehicles are not suitable for postal use. We do foresee with the electrics that we would need a specialty type of vehicle.

Mr. Crane. I might add one thing.

Mr. Ottinger. Yes.

Mr. Crane. We are testing several other types of vehicles. We have three vehicles at work in Norfolk, Va., test vehicles. We are also testing a conversion that was put together in Texas, Amarillo, Tex. We are using some electric vehicles for security purposes in Miami, Florida. We are not locked into one type of vehicle at all. We are asking our research and development people to look for electric vehicles with better operating characteristics than what we are buying. We are interested in many types.

Mr. Ottinger. If we pass this legislation, as presently drafted, would it help you in being able to use a wider variety of vehicles? If not, are there changes that you would like to see in this legislation so that you could expand the work that you have already begun in such a salutary way?

Mr. Crane. From a fleet standpoint, sir, the wider the different types of models that we have, the more difficult the maintenance becomes. We would prefer to concentrate on a limited number of models of vehicles.

When we have to buy in quantity, which is something that we must do—we must buy something like 16,000 vehicles a year to stay even with our vehicle fleet requirements—from the standpoint of maintenance, we try to keep the numbers of models limited. We do not want the proliferation of a wide number of widely divergent vehicles.

Mr. Ottinger. Would you like to see a provision in the bill that would permit you to purchase, and for us to pay the cost differential on a given quantity of electric or hybrid vehicles, Mr. Braughton?

Mr. Braughton. I believe that the provision is there for ERDA to cover the cost between conventional and the other, Mr. Ottinger.

Mr. OTTINGER. You say that there are special requirements that would make it difficult for you to qualify. What I would like to, perhaps, work with you, and I do not want to take more of the committee's time now, but we want to see if we can help you in meeting your requirements.

Mr. BRAUGHTON. Maybe I did not make myself clear. I was talking about having a wide variety of vehicles. I was not talking about the funding. We would prefer a more limited number of vehicles, sir, rather than to have a wide variety.

Mr. OTTINGER. Could you submit for the record a commentary on what is needed in the bill to be more effective to help to meet your requirements so that we could work something out that would be advantageous in terms of our objectives to promote the electric vehicles and your objective of getting a more effective set of vehicles for the Postal Service?

Mr. BRAUGHTON. Yes; I will do this.

Mr. OTTINGER. Thank you.

[The information requested follows:]

It is not possible at the present time for Federal agencies to consider competitive vehicle procurements on the basis of comparative life cycle costs and beneficial emission characteristics, because there are yet no valid statistical data. However, we understand that the bill is intended to encourage agencies to begin to buy electric vehicles immediately. If that is the case, it would seem that section 8 should provide authority for ERDA to pay the difference between the original purchase prices of electric and internal combustion engines, since that differential is the one now confronting agency planners who have to justify to their agency a proposed investment. To accomplish that result, section 8 could be revised to read as follows:

"The United States Postal Service, the General Services Administration, the Secretary of Defense, and the heads of other Federal agencies shall arrange for the introduction of electric vehicles into their fleets as soon as possible. In any case where (as determined by the head of the agency involved) electric vehicles are practical but not economically competitive with conventional vehicles, the Administrator may pay the difference between the original purchase price of an electric vehicle meeting the design requirements of the user (including the cost of the original battery), and the original purchase price of an internal combustion engine vehicle of like capacity and function (as part of the demonstration program under section 7) to insure that the maximum number of electric vehicles are placed in use by Federal agencies. As reliable comparative cost data with respect to life cycle costing and beneficial emission characteristics become available, the determination of the incremental cost paid by the Administrator to make electric vehicles economically competitive with conventional vehicles shall take such data fully into account."

Mr. HECHLER. Will you yield?

Mr. OTTINGER. Yes.

Mr. HECHLER. Is the Postal Service subject to the overall umbrella of the OMB in determining whether your position on legislation is in conformity with the program of the President? What I seek is whether your position on this legislation is in any way influenced by the OMB's feeling toward H.R. 5470?

Mr. BRAUGHTON. I cannot answer that.

Mr. HECHLER. You have taken a position on 5470. I am trying to find out if it is the Postal Service's position or if you are influenced by the overall negative attitude that appears to be held by OMB?

Mr. BRAUGHTON. Our position is that the main thrust of the bill, goes beyond our experience. It is primarily designed to deal with traditional passenger-type vehicles used by the general public for commuting or normal business travel. Our experience with electric vehicle purchase and utilization is narrowly limited to a particular type of vehicle made according to postal specifications and designed for fleet operation use in the delivery of mail.

Mr. HECHLER. Your answer is no; that OMB has not influenced your testimony or position?

Mr. BRAUGHTON. We are aware of OMB's attitude toward the bill; yes.

Mr. OTTINGER. Are you a Government agency for the purposes of this bill so that you would qualify under the bill?

Mr. BRAUGHTON. I don't understand the question.

Mr. OTTINGER. The bill provides that ERDA pays for the Government agencies—well, are you a Government agency?

Mr. BRAUGHTON. Yes, sir.

Mr. BROWN. Now, Mr. Braughton, if, in its wisdom, the Congress should decide to mandate the electric vehicles for postal deliveries in high air pollution areas of the country and this represented 20 percent of your area or your business, what would that mean in terms of the procurement of electric vehicles nationwide for the Postal Service on an annual basis?

Mr. BRAUGHTON. It is difficult to estimate this.

Mr. BROWN. Do you have a rough figure as to what you purchased each year in terms of the small postal delivery trucks that at this time we are actually talking about?

Mr. BRAUGHTON. Yes; approximately 16,000 per year. This is, essentially, sir, for replacement purposes for the fleet. We do know that there are limitations on where the existing electrics can be located.

Mr. BROWN. Such as hilly areas or long-distance situations?

Mr. BRAUGHTON. Yes; or where we have heavy snow or inclement weather. There are limitations. Also, even in the area such as southern California, there may be particular areas where the vehicle, to transport the carrier from the delivery area, might have to travel over high-speed highways where, presently, we would not consider it advisable for the electric vehicles to go. There are several factors here that would limit the estimate of the number that we would use.

Mr. BROWN. You mentioned the 16,000 per year for the replacements. What is the total size of the fleet?

Mr. BRAUGHTON. About 65,000 of our existing fleet are in the quarter-ton area.

Mr. BROWN. Thank you.

I think that we can make some calculations from those figures. You are undoubtedly aware that a crucial aspect of the matter is the obtaining of accurate life cycle cost on the electric vehicles.

Mr. BRAUGHTON. Yes, sir.

Mr. BROWN. Are you relatively confident that you are assembling the best data that you can on the vehicles in use as to the life cycle cost?

Mr. BRAUGHTON. Yes. We are now receiving deliveries. The first vehicles have not yet been put into operation. Yes. We will be working with our field people in developing good, hard information that we can use. We will share this information with ERDA and the other agencies.

Mr. BROWN. We are very anxious to be assured that the data that you are getting on maintenance and operating costs and the depreciation and so forth, that this can be substantiated. It provides a basis for further policy decisions that we will be wanting to make.

Mr. CRANE. Our accounting system is very precise. Every vehicle that we have has a discrete code. The new electric has such a discrete code so that every cost incident to it will be recorded and watched carefully, sir. As to the specification; it requires that the battery last without cost to the Postal Service for 4 years. That already is locked in. Even though the battery might fail, AM General or Gould will provide new batteries during this span of time. We do anticipate that the batteries will last much longer.

I would recommend that the committee possibly may, perhaps, explore the life cycle cost history of the British electric industry. It is a very large industry. It is a very effective or cost-effective industry, particularly in the dairy business in London.

Mr. BROWN. Mr. Frey, have you any questions?

Mr. FREY. No. Mr. Chairman.

Mr. BROWN. Mr. Goldwater.

Mr. GOLDWATER. Thank you, but I have no questions at this time.

Mr. BROWN. Thank you very much, gentlemen. If we have any further questions, we will communicate with you in writing. We do very much appreciate your testimony. I hope that you will make a point to keep the committee staff informed as you develop operating results from your experiences as you communicate that to ERDA. We would like to know about it.

Mr. CRANE. Yes.

Mr. BRAUGHTON. Yes, sir.

Mr. BROWN. Our next witness this morning is Mr. Cruse W. Moss, the president of AM General, the company which supplies the vehicles which have just been discussed.

We are delighted to have you here at this time to report your own experience in this field. Your testimony will be incorporated into the record in full. You may proceed with it in whatever fashion you wish.

STATEMENT OF CRUSE W. MOSS, PRESIDENT, AM GENERAL; ACCOMPANIED BY JAMES H. DRUM, VICE PRESIDENT, GOVERNMENT AFFAIRS, AND ROBERT E. CREGER, DIRECTOR OF MARKETING

Mr. MOSS. Thank you, Mr. Chairman. I am accompanied by Mr. James H. Drum, vice president of Government Affairs for our company and Robert E. Creger, director of marketing for our company.

Mr. BROWN. Your complete statement will now be inserted into the record.

[The complete prepared statement of Cruse W. Moss is as follows:]

STATEMENT OF CRUSE W. MOSS, PRESIDENT AM GENERAL CORPORATION

Chairman McCormack and members of the subcommittee; my name is Cruse W. Moss and I am president of AM General Corporation, a subsidiary of American Motors Corporation. We appreciate the opportunity to comment on the proposed electric vehicle research, development and demonstration act. We believe it is forward-looking legislation which will substantially accelerate development of electric-powered vehicles in the United States.

AM General Corporation was the successful bidder to the United States Postal Service for 352 of our electrucks, like the one on display here yesterday. The electruck is an electric-powered version of our ¼ ton delivery vehicle. We are a major supplier of vehicles to the Postal Service, currently building 60 Postal Service units per day on a contract for which we competed and were the successful bidder for 28,490 units. In January of 1976, AM General will build its one hundred thousandth Postal Service vehicle for service in the United States.

To further explain AM General's position in the automotive industry, I might mention that we are also a major producer of tactical vehicles for the United States and the free world, and also are a major manufacturer of urban transit buses.

It seems clear that a goal of this act is the conservation of energy. I would like to compliment the committee on your far sightedness. Most assuredly, this piece of legislation will be all important to a forthcoming national energy policy. I feel, to choose any particular combination of energy strategies without careful thought and analysis could well compound the country's present energy difficulties. An adequate national energy policy must of course rise from basic decisions made by and on behalf of the country as a whole—decisions concerning national security, cost, and the present and future quality of life in the United States. When those decisions have been made, a national plan will clearly spell out firm avenues and operational strategies, which would include the degree of dependence on foreign oil supplies, environmental standards and the balance between exploration and conservation of national resources.

Our strategic options for attacking the present energy problems are relatively limited and very simple. We can do one of two things—first, we could sharply restrict energy usage, or second, we could partially shift from our present reliance on oil and gas to an energy base of more abundant fuels.

The primary energy for recharging electric vehicle power systems could come from coal which is a more abundantly available source of energy in the United States today than oil or natural gas. What you are proposing to do is to more closely align our energy usage rate to our resources.

In our search at AM General for profitable avenues of diversification, we have been gathering for some time all available data and information on electric vehicles and electric vehicle markets. It is our judgment, initial concentration in electric vehicle development should be in those types of vehicles suitable for fleet use.

There are several reasons for concentration on fleet vehicles. Most importantly, some tasks of large fleet users such as utilities, delivery firms, and the postal service fall easily into the operating capabilities of current state-of-the-art electric vehicles. Many of the vehicles which fall into that category are used in routes which, generally speaking, could be called "closed loops," allowing the vehicles to return to a central point each night for recharging. Thus with fleet users, electric vehicles can be designed, developed and operated in a fairly well controlled environment. In this situation, the vehicles can be continually refined to improve range and speed.

The fleet market in the United States has a magnitude of several hundred thousand urban delivery vehicles operated by both Government and private companies, which are possibilities for electric powered vehicles today. Most of these vehicles operate in a 20 to 50 mile range.

Well within performance characteristics of present-day state-of-the-art electric vehicles are large utility fleets. In 1972, one large utility had a vehicle fleet totaling 151 thousand vehicles, and 165 thousand in 1973. According to data we received from that company concerning their fleet, approximately 93 thousand vehicles are vans, 63 thousand of those are classified in the urban or short-range categories. Daily mileage generated averaged 8.3 to 39 miles. Fuel consumption varied from an average of 4.1 to 12.8 miles per gallon. The performance characteristics of these vans approximate electric vehicle performance.

The performance criteria of that utility fleet closely coincides with that of the postal service. Donn T. Crane, fleet management director of the U.S. postal service, has estimated that as many as 30 thousand of the postal service vehicles could be replaced by electric vehicles.

Under the act, the administrator must develop performance standards and criteria for the needs of passenger vehicles and urban commercial vehicles.

AM General looks forward to working with the administrator. We have already met the criteria set by the postal service and strongly feel, as I have stated, that those criterion also apply to a segment of the commercial fleet market. The act calls for other Federal agencies, including the General Services Administration, and the Department of Defense to use electric vehicles. AM General has already met with GSA on the subject of electric vehicles and has worked closely for many years with the Department of Defense.

We would propose to enter into a multiyear contract with the Energy Research and Development Administration to furnish electrucks for the vehicle fleets of State and local governments and Federal agencies. The agencies operating those vehicles should undertake studies relative to operating costs, life cycle costs and the energy demands placed on the electric utilities for energy both during peak hours and off-peak hours.

AM General is uniquely suited to be of service toward the goal of fulfilling the objectives of this act for the following reasons:

We have already made a substantial investment in research and development of electric vehicles. We have made a significant investment in plant and facilities. We are presently producing electric vehicles concurrent with internal combustion engine vehicles on the same assembly. Further, AM General has a history of working closely with governmental agencies concerning the development of special vehicles.

Much remains to be done to make electric vehicles practical from a broad transportation standpoint. But there is no question that answers can be found. The real unknown is how long will it take. Without question the proposed legislation could enable AM General to compress that time frame. Equally important it could demonstrate how industry/Government cooperation can produce needed improvements not only in the shortest possible time but at the least possible cost to the public.

Thank you.

Mr. Brown. Thank you very much for your testimony. It is extremely helpful to the committee.

Do you have any questions, Mr. Goldwater?

Mr. Goldwater. Thank you, Mr. Chairman.

Mr. Brown. You do not drive an AMG, do you?

Mr. Goldwater. No; but I have, and they are good vehicles, Mr. Chairman.

What amount of the demonstration program do you feel should be allocated to the commercial vehicles?

Mr. Moss. Self-serving, I would say the majority of it. However, on a practical basis, I think that the answer should also be a majority of it. Those applications that I outlined in my testimony and that Mr. Crane outlined, are applications that are controlled, the environmental operational types, that is, in that they can be closed loop or climatically controlled, geographically controlled, or deployed where electric vehicles can perform at their best or at their optimum.

Mr. Goldwater. You mentioned that you are currently producing the postal vehicle along with the others on the same assembly line. Could you explain and elaborate a little more on this system, for instance, where you have both assembly lines going at the same time.

Mr. Moss. It is unique. We have made the investment in plant facilities to produce quarter-ton units for the Postal Service. We are able to assemble the electric vehicles on line in the same plant. This is by merely installing the electric propulsion system. It is the same procedure.

Mr. GOLDWATER. Does this, perhaps, present a problem for the automobile industry?

Mr. MOSS. Not particularly. It might in some plants. In this plant that was designed specifically for this type of assembly operation, there is no particular problem.

Mr. GOLDWATER. Is there something unique about the assembly of electric versus the internal combustion?

Mr. MOSS. It is an entirely different propulsion system. It is not unique in the manufacturing process where we make installation.

Mr. GOLDWATER. Is it more complicated or elaborate, Mr. Moss?

Mr. MOSS. Yes; it is more complex. This is installed as a unit in the plant. The vehicle does not present any problem, sir.

Mr. GOLDWATER. What about your assemblers, your workers, is there some special problem to train or to retrain them, Mr. Moss?

Mr. MOSS. We use a different station to make the actual installation. We use different people. There is no particular training problem.

Mr. GOLDWATER. How many vehicles, and on what schedule could you produce if the demonstration went forward? What would be your maximum amount?

Mr. MOSS. At this plant on a one-shift basis, it could produce 120 quarter-ton units per 8-hour shift. On a one-shift basis, that is close to 30,000 units a year. We could produce any percentage of those as electric. I think the controlling factor on how many electrical vehicles that we could produce would be the availability of the components from Gould. I think that our current estimates would supply in the area of 30 per day. We are talking about one-fourth of that, 7,000 units per year, a theoretical first-year potential, Mr. Goldwater.

Mr. GOLDWATER. I do not know if you read Dr. Kane's testimony yesterday. He discussed the life cycle cost of the electric versus the internal combustion engine. I am wondering what really has been your experience. How long have you had the electrics in the Postal Service?

Mr. MOSS. We delivered something over 100. As Mr. Crane indicated, I don't believe that they are in service as yet, sir.

Mr. GOLDWATER. Not as yet?

Mr. MOSS. No, sir.

Mr. GOLDWATER. You have not had an opportunity to fully evaluate them?

Mr. MOSS. No. That is, with the exception of the data we obtained from the largest dairy operation in Great Britain, which operates some 4,000 electric vehicles, of which 2,500 are in operation in London. Their director of maintenance has been in contact with Mr. Creger. He indicated the life cycle cost on their computation is about half of the petrol fleet. They have documented this to Mr. Creger in a letter. This has been figured over quite a long period of time or experience, Mr. Goldwater.

Mr. GOLDWATER. Have you studied this question in any depth? The point that was made by the study in Los Angeles, that as electric goes forward, we will also refine the internal combustion engine. Is there going to be a cost benefit in terms of economy and operations; also in terms of air pollution? Will electric actually make that much contribution, such as quality of air and cost-effectiveness, say, in the operation of the vehicle?

Mr. Moss. In pollution control, certainly the electric vehicle unit is virtually pollution free. When you consider the relatively small number of electrics that will be introduced in the total system, I would say this would have a very slight effect in, say, southern California, well, there are 300 going into San Bernardino. This would be a fraction of one-tenth of 1 percent.

Mr. Goldwater. What kind of predictions can you make on the internal combustion engine? You produce a lot of cars with internal combustion engines. Are you going to refine and improve this type of propulsion?

Mr. Moss. We have continuous research and development. This is in order to meet the standards required under the EPA. I cannot specifically tell you any specific research activities we have, sir, or what it is that we plan to achieve. We are, obviously, working very hard on it.

Mr. Goldwater. We could very well conclude that we are not going to refine the internal combustion engine to the point where it will be absolutely pollution free. In fact, we could conclude that the electric is important here as far as the air pollution is concerned.

Mr. Moss. I think it is very important with regard to the air pollution. In the near future, I don't think that the quality of air will be appreciably enhanced by the small number of electric vehicles going into the system.

Mr. Goldwater. Since we touched on the assembly line question, and I think that one of our concerns is when we make the transition to electric, what about the assembly line? What will it cost? What is involved in tooling up and retraining?

Mr. Moss. We have made the investment to produce electric vehicles.

Mr. Goldwater. We are interested in your experience; we want to benefit by your experience. Perhaps you could submit this in more detail as to what is involved and what it will take or cost in order to build this. I want to thank you very much.

Mr. Moss. We will submit this later.

[The information requested follows:]

Concerning the magnitude of investment necessary to economically and efficiently manufacture electric vehicles, I offer the following information to the Subcommittee.

AM General facilitized and tooled one of its plants for approximately $6,000,000 to build the unique Postal Service one-quarter ton gasoline-powered delivery vehicle. That investment was to manufacture, on a one-shift basis, up to 120 units per day. That investment was for the manufacturing process only and does not include the investment of buildings and land.

Because the AM General Electruck is so uniquely similar to its gasoline-powered vehicle, the additional investment in tooling to build the electric vehicle was somewhat less than $1,000,000. It is for this reason, the size of the additional investment, that allowed AM General to sell its electric vehicle to the Postal Service through the competitive bid process for approximately $600 less per unit than the next lowest bid.

It is the unique similarity of our two vehicles that allows us to build these two units concurrently on the same assembly line. If that were not the case, then the magnitude of investment to build electric vehicles would be very substantial.

Mr. Brown. Now, Mr. Goldwater has opened up the question of the life cycle cost, a matter which was taken up with several witnesses. I think that the previous witness referred to the experience with the British electric vehicles in their milk delivery setup over there.

Apparently you have, through Mr. Creger, received some data on life cycle cost and battery life. Could either you or Mr. Creger give us, or amplify on that subject a little bit, please. If you would like to provide additional information later for the record, whichever is more convenient for you, you may do this. But this is a matter of crucial interest to the committee.

Mr. Moss. Mr. Chairman, we could do that. We would be glad to submit the information that we obtained. The dairy company was the company I had reference to. We had correspondence with Mr. Pearson, their director of transportation. We will submit this data.

[The information requested follows:]

In response to a question concerning life-cycle costs of electric vehicle versus internal combustion engine vehicles, I stated that AM General had data received from Mr. George E. Pearson, Director—Transport, Express Dairy Co. (London) Ltd., in which Mr. Pearson computes the life-cycle costs of EV's vs. ICE's. His data indicates the life-cycle cost for the electric vehicle is approximately half the cost of the ICE vehicle per mile traveled.

We have corresponded with Mr. Pearson's office and obtained that company's permission to pass on to you a copy of a presentation given by Mr. Pearson at the 44th Annual Convention of the Battery Council International. This presentation includes Mr. Pearson's computations.

I feel that the quantitative data from Mr. Pearson are far more qualitative than data available from the study made in Los Angeles to which Mr. Goldwater referred. It is my understanding that life-cycle costs indicated in that study were distorted because it was assumed that gasoline prices would decrease in the future because of the removal of federal and state taxes. That assumption would appear to me to be incorrect.

Mr. Brown. You said that you received information from him that the cost for the electric vehicle is one-half of that of the internal combustion engine.

Mr. Moss. He detailed his method of computation.

Mr. Brown. We are interested in the details. The table in the study on electric vehicles in southern California on the life-cycle car cost compares this with the electric cars, using various types of batteries, including the lead acid. I assume that they are using lead acid?

Mr. Moss. Yes.

Mr. Brown. Is that correct?

Mr. Moss. Yes; the industrial type.

Mr. Brown. The figures indicate that the lead acid is at least 50 percent more costly on a cents per-mile lifetime costing basis. It is important to have other data bearing on this, particularly the knowledge on how it was obtained.

Mr. Moss. As I said, I will submit it.

Mr. Brown. How much of the assembly is produced by your company and how much is subcontracted? Specifically, you get batteries from Gould. Where do you get the propulsion units and the control systems?

Mr. Moss. All electric propulsion batteries and an electric controller are supplied by Gould.

Mr. Brown. Do you provide all of the rest?

Mr. Moss. Yes. We manufacture it.

Mr. Brown. Mr. Hechler.

Mr. Hechler. Thank you for the strong plug that you made on the bottom of page 2 for coal. AM General has made a substantial investment in research and development in the electric vehicles.

I wonder if you could tell us, aside from the battery development, what are the areas of research and development that you feel that ERDA could undertake in this area that would speed up the practical utilization, the commercial utilization, by the Federal, State, and local governments of electric-powered vehicles?

Mr. Moss. I think that the principal area is, as you outlined, batteries. The direct current motor or the electronic control system, are all well refined. The state of the art is very advanced. I think that ERDA's principal thrust is in the battery area.

Mr. Hechler. The committee has increased funding in the battery area. We welcome any suggestions as to any other areas for additional emphasis.

Mr. Moss. Our opinion on that would be the total vehicle systems area. It could be undertaken by private industry. I think the area in which the Federal funds could bring into play, would be in the area of batteries.

Mr. Hechler. You consider, I assume, the investment you made as a good investment, that is, the private funds?

Mr. Moss. Yes; we believe that it is. We have made an investment that is applicable to either the IC or to the electric vehicle. We have made an investment. We do consider that what we have done for the electric vehicle is a good investment.

Mr. Hechler. Could you give us a ball park, a percentage figure, as to this?

Mr. Moss. I don't think that I could. I don't think that I have that information.

Mr. Hechler. Thank you.

Mr. Brown. Mr. Ottinger.

Mr. Ottinger. Mr. Chairman, thank you, but I have no questions.

Mr. Brown. Very well, I think that those will be all of the questions that we will have, that is, except for the additional information which you agreed earlier to supply to us.

Mr. Moss. Yes, sir.

Mr. Brown. If we think of some additional questions for you, we will write to you. Thank you.

Mr. Moss. Thank you, Mr. Chairman.

[Answers to additional questions submitted to Mr. Moss follow:]

Question #1

Is there a need for a Federal role in aiding the electric vehicle industry?

Answer

Electrically powered vehicles are not now economically competitive on a first cost, vis-a-vis conventional internal combustion engine powered vehicles and the time required for research, development, production, customer acceptance and build-up of a service and repair structure is much greater than generally realized. A substantial degree of assistance from the Federal Government is needed if there is to be a substantial market acceptance of electric vehicles. The Federal Government might, in order to increase the number of transportation options available, consider the following steps to hasten the acceptance of the electric vehicle into the marketplace.

1) Make the maximum possible use of electric vehicles in Federal fleets.

2) Provide preferential subsidies for purchases of electric vehicles by Federal, State and local governments.

3) Provide preferential subsidies or tax reductions for privately owned public transportation systems or utilities for using electric vehicles.

4) Continue to sponsor legislation such as H.R. 5470.

Question #2

What are the best means of procurement for vehicles in order to ensure a fair mix of companies will be able to participate?

a) Will low-capital companies be able to compete in straight competitive bidding, in the sense of being able to finance their bids against possible future sales and subsequent recovery of set-up costs?

b) Would loan guarantee provisions better enable such companies to raise needed capital?

c) Will patent provisions, delivery schedule, or contract penalty provisions inhibit particular kinds of companies from participating?

d) Should there be a specification that fixed numbers of vehicles must be supplied by companies less than a given size -- and/or that fixed numbers of vehicles in given price ranges should be purchased -- in order to ensure participation by a broad range of companies?

e) Would excessive reliance on small business tend to waste the productive capacity available from the large auto manufacturers, and unnecessarily increase costs of initiating a strong electric vehicle industry?

f) What change in safety or import regulations may be necessary to enable a variety of companies to participate?

Answers to 2. a) and d)

Based on potential markets, defined primarily as light vans, in my opinion there is very little likelihood that electric vehicles will have a significant and continuing impact on major internal combustion engine producers, research and development or production activities. While research and development programs have been valuable in determining the role of electric vehicles, the dollars expended have been very low in comparison with those spent for research on internal combustion engine vehicles.

Moreover, most current engine and power plant work is emphasizing improvements in internal combustion engine fuel economy and consolidation and simplification of pollution reduction devices.

With regard to production, the crossover from limited tooling and limited production of vehicles to full tooling and mass production is variously estimated to be economical somewhere in the annual production range of 50,000 to 100,000 vehicles of a single type. The outlook for attracting major automotive manufacturers larger than AM General does not seem to exist.

On the other hand, to rely solely on small companies or low capital companies would detract from the overall program because of the following:

1) There would be a duplication of production capabilities.

2) The inherent high cost of low production quantities would inhibit the success of the program. The initial first cost of electric vehicles is not now competitive with the initial first cost of internal combustion engine vehicles. The magnitude of the initial first cost price differential now varies from 30% to 50%.

Answer to 2. b)

To specifically answer portions of the second question, without doubt, loan guaranty provisions would enable small or low capital companies to raise needed capital.

Answers to 2. c) and f)

AM General foresees no difficulty in the area of potential patent problems, nor does AM General foresee any need for change in current import regulations. With reference to the question on safety, I shall address my answer to the question of safety in response to your question No. 7.

Question #3

What is the long range environmental implication of electrification of transportation?

a) Does an implied centralization of energy production have negative as well as positive ramifications? How do these balance against elimination of mobile combustion pollution sources?

b) What are the short and long-term alternatives to transportation electrification?

Answer to 3. and 3. a)

The United States Environmental Protection Agency has predicted that the increasing concentration of population in urban areas and the growing number of vehicles in operation within these areas will neutralize the improvements being made in the emission levels of new internal combustion engine vehicles. With their freedom from atmospheric emissions, electric vehicles therefore seem uniquely suited for some missions in both public and private transportation in the urban areas.

Another very important factor favoring electric vehicles is the location of the electric power plants that provide energy for electric vehicles. Generally, these plants are removed from the urban centers where air quality is a major concern and further, the emissions from such plants are more easily reduced than the emissions from a large magnitude of moving vehicles.

Still another advantage of the electric vehicle is its freedom from noise, and this once again emphasizes environmental advantages of electric vehicles, particularly in delivery vans.

Answer to 3. b)

There does not seem to be a viable long-term alternative to the electrification of a portion of the vehicles in service in the United States. There is a tremendous disparity in the use of oil and gas compared to the resource base in our country. Natural gas accounts for only 2% of fossil fuel resources, but 32% of our total energy usage; petroleum is 3% of resources and 36% of demand. By contrast, coal accounts for 90% of our fossil fuel resources but only 17% of our usage. If our program of national energy independence is to work, we must make better use of our most abundant reserves, coal.

Question #4

Will provision of maintenance facilities for electric vehicles be a major problem in their widespread adoption?

Answer

As I stated AM General's position in my testimony on June 4, and as I have indicated earlier in this letter, we have compiled data that indicates there will not be a widespread mass adoption of electric vehicles near term. It is this mass market that would need thousands of service station-like maintenance facilities.

There is, however, a segment of the vehicle fleet which is immediately available to electric vehicles in the present day "state-of-the-art". We should address the demonstration itself to the market segment of the light delivery van, primarily made up of Postal Service vans, utility vans, etc. The vast majority of these vehicles are operated by fleets which operate their own maintenance facilities. The adoption of AM General's recommendation would, therefore, circumvent at this time the maintenance facility problems which would be immense if electric vehicles were marketed through the broad vehicle mass market.

I would like to re-emphasize a portion of my testimony relative to this point. On June 4, 1975, a portion of my statement was as follows:

> "In our search at AM General for possible avenues of diversification, we have been gathering for some time all available data and information on electric vehicles and electric vehicle markets. It is our judgment that initial concentration in electric vehicle development should be in those types of vehicles suitable for fleet use.
>
> There are several reasons for concentration on fleet vehicles. Most importantly, some tasks of large fleet users such as utilities, delivery firms and the Postal Service fall easily into the operating capabilities of current state-of-the-art electric vehicles. Many of

these vehicles which fall into that category are used in routes which, generally speaking, could be called "closed loops" allowing for the vehicles to return to a central point each night for recharging. Thus, with fleet users, electric vehicles can be designed, developed and operated in a fairly well controlled environment. In this situation the vehicles can be continually refined to improve range and speed.

The fleet market in the U. S. has a magnitude of several hundred thousand urban delivery vehicles operated by both Government and private companies, which are possibilities for electric powered vehicles today. Most of these vehicles operate in a 20 to 50 mile range.

Well within the performance characteristics of present day state-of-the-art electric vehicles, are large utility fleets. In 1972 one large utility had a vehicle fleet totaling 151,000 vehicles and 165,000 in 1973. According to data we received from that company concerning their fleet, approximately 93,000 vehicles are vans, 63,000 of those are classified in the urban or short range categories. Daily mileage generated averaged 8.3 to 39 miles. Fuel comsumption varied from an average of 4.1 to 12.8 miles per gallon. The performance characteristics of these vans approximate electric vehicle performance."

Question #5

Could the national goals be best met by means of a cooperative effort among the large and small manufacturers -- for example, through the production of chassis and other components respectively?

Answer

I think I can best answer that question by pointing to AM General's Electruck. AM General was the successful bidder in competitive bidding by a margin of approximately $600 per vehicle for 350 Postal Service vehicles.

In my opinion, the reason AM General was able to offer to the Postal Service this reliable vehicle at this very competitive price was because we, AM General, researched electrical component manufacturers and, after close scrutiny of both product and price, chose as our subcontractor, a company which complements our own areas of expertise. Therefore, in essence, the Postal Service received the technical expertise from two highly specialized companies. Rather than a component manufacturer having to build his own vehicle which would be a duplication of production capacity, and rather than AM General duplicating research development and the production capability of electrical components, the Postal Service received at a low cost the best elements, efficiencies and expertise that each company had to offer.

In the competitive marketplace, it therefore is not a question of large and small manufacturers cooperating or competing. It is truly an exercise of economics, and the free enterprise system.

Question #6

Is the timetable of the program appropriate? Should Phase 1 (conventional chassis) be eliminated or compressed in view of the current state of the industry?

Answer

I understand the primary goals of the legislation to be twofold; a three-year program to demonstrate the commercial capability of electric vehicles in two phases, the first to be the introduction within one year of several thousand electric powered vehicles using existing state-of-the-art chassis; the second phase would involve the production of several thousand vehicles designed from the ground up as electric vehicles.

As I indicated in my testimony on June 4, AM General is now able to fulfill your vehicle requirements spelled out in Phase 1 of your goals. We have at this time a vehicle competitively priced, reliable, and are in a position to manufacture from 20 to 30 electric vehicles per day.

Further, AM General has a continuing program of product refinement research and development.

To summarize my response to this question, let me reaffirm that a compression of the Phase 1 time frame is possible, from AM General's point of view, by taking advantage of the resources and production capabilities available already in the automotive industry.

Question #7

What are the special safety problems?

a) Are electric vehicles safer in some respects, so that current vehicle regulations might be relaxed?

b) Are there hazards (as sulfuric acid spills,...) that ought to be specifically addressed?

Answer to 7. a)

Federal Safety Standards will have a substantial effect upon electric vehicle designs. According to the National Highway

Safety Administration, all new passenger cars, domestic and foreign must comply with the Federal Motor Vehicle Safety Standards.

Under Section 119, the Secretary of Transportation is authorized to issue, annul and revoke such rules and regulations. Of those standards now in effect, there is one notable that should be carefully reviewed. I feel the electric vehicle industry can build a strong case for a change insofar as electric vehicles are concerned. However, the electric vehicle industry should not develop any illusions that it can escape many of the Federal Safety Standards.

I refer to Standard No. 109 which has to do with new pneumatic tires. This standard specifies tire dimensions and laboratory test requirements for bead unseating resistance, strength, endurance and high speed performance. It further defines tire load rating and specifies labeling requirements.

In that electric vehicles are essentially operated at low speed and do not have the capability of high speeds, portions of this standard should be annulled for electric vehicles. As an example, the tires used on AM General's Electruck must pass strict high-speed tests. Tire companies should be encouraged to build and have available for electric vehicles, tires which meet the appropriate specifications under the standard but need not adhere to the high-speed test performance and, therefore, could be manufactured for a low drag road "resistance" factor.

Answer to 7. b)

We know of no specific hazards to be addressed at this time relative to sulfuric acid spills from the battery insofar as the AM General Electruck is concerned. Of course, vehicle construction would vary from manufacturer to manufacturer. In the AM General Electruck, the conventional metal "firewall" separates the driver from the battery the same as the firewall separates the driver from the conventional internal combustion engine. Of course, there are hazards having to do with high electrical voltage used for recharging purposes. The inherent risk, however, would appear to me to be no higher than the risk involved in refueling a conventional vehicle with highly combustible gasoline.

Question #8

What might be the impact on labor. Will a new, possibly labor intense, industry come about with the growth of the electric vehicle market.

Answer

I do not feel there will be, in essence, a new industry. It is my opinion that the numbers of electric vehicles sold will simply replace a nearly like number of internal combustion engine vehicles which would have been manufactured for the marketplace.

In essence then, an electric vehicle would replace an internal combustion vehicle and the production capacity of the industry will be relatively unaffected by the impact of electric vehicles.

Question #9

For long-range transport, should we take the "car (E-V)" -- or other mass transit -- approach rather than using petroleum to meet the extended range?

a) Or, should we have electrified road-ways? (These would have the advantage of eliminating energy wasted in transporting the weight of batteries).

b) Should electric mass transit be incorporated into the demonstration program?

c) Please comment on the possible role of the fuel cell?

Answers to 9. a) and b)

It seems to me to be a great risk in the proliferation of objectives and approaches if, in fact, the objective of H.R. 5740 is the demonstration of electric vehicles.

Great care must be given so that in the demonstration of electric vehicles, they fit the vehicle mission they are detailed to perform. That is the reason that throughout my testimony on June 4 and throughout my letter to you dated July 23, I have reiterated that for the successful completion of the demonstration of electric vehicles under this Bill, a carefully modulated narrow scoped mission must be defined. A proliferation of other adjunct possibilities, although intellectually interesting, would prove to be, in my opinion, the undoing of the demonstration phase of this act.

This Bill is uniquely suited to show the American public, and in particular the fleet owners, that an electric vehicle can perform the mission of many internal combustion engine commercial vans and that if cost effectiveness is gauged on lifecycle costs, that electric vehicles can also be cost effective.

Answer to 9. c)

As a primary vehicle manufacturer, AM General to date has had little input relative to the fuel cell. I feel it would therefore be inappropriate for me to comment on that portion of this question because of a relatively low base of information.

Question #10

What are the basic objectives of technological demonstration programs and what general criteria must be recognized in establishing and planning such programs?

a) Given the above general objectives and criteria, exactly how do they relate to the proposed E-V program?

b) What schedule (time) and size is appropriate for the E-V program? Why? Some of the witnesses suggested one and three years were too short for the two phases of the demonstration program. Given the current state of the technology, what real accomplishments are possible within this time frame?

c) If the program were delayed until advanced batteries were available, what would be the benefits of the program? How would these benefits differ from those of an earlier program? What would be the costs and disadvantages of such a delay?

d) What would be the advantages and drawbacks of having a demonstration program proceeding in parallel to advanced battery development? What time scale is likely and reasonable for each?

e) What are the non-technological benefits of the demonstration program; could they be realized with today's batteries?

f) How, exactly, does current cost-effectiveness relate to the objectives of the demonstration program? How would your response be affected by given future cost increases in petroleum; in cost decreases in electric vehicle component and manufacturing?

Answer

Three paramount objectives must each be clearly defined and a criteria narrowly established so that meaningful data can be gained from the program.

The three primary areas of which I speak are:

a) Operational characteristics and capabilities of electric vehicles by 1) present state-of-the-art, 2) in relation to the potential future improvements insofar as range and speed are concerned.

b) The economics of electric vehicles as it applies to life-cycle costs, initial cost, maintenance cost, battery recycling, etc.

c) The marketability of electric vehicles by market segment and sub-segment.

All three of these areas will benefit greatly by the receipt of meaningful data. It is only through Federal participation in the form of such a Bill as H.R. 5470 that a sufficient quantity of vehicles will be put into service from which meaningful data can be derived.

Answer to 10. a)

As I have previously stated, it is our firm conviction that the application, particularly in a demonstration phase, must be in those areas where the criteria of the mission of the vehicle clearly demonstrates that an electric vehicle can dutifully take the place of an internal combustion engine vehicle.

Answer to 10. b)

One thrust of the demonstration is to categorically demonstrate that current state-of-the-art electric vehicles can perform the missions of a large number of internal combustion engine vehicles. AM General strongly feels that this can be demonstrated particularly in the light van market segment. The time frame to accomplish the demonstration portion of Phase 1 is adequate because of the substantial research and development and the establishment of production facilities already accomplished.

Answer to 10. c)

I can see no worthwhile reason to delay the program. The main benefit derived will be the gleaning of valuable data concerning market segment, market size, performance, and life-cycle cost. All this can be accomplished now. It would seem inappropriate to wait for more advance battery technology. The research and development of battery technology should be going on simultaneously and in tandem to the marketing phase of the program.

Answer to 10. d)

The advantage of having the demonstration phase of the program parallel the advanced battery development program would be the early usage of input data from the demonstration phase to the battery development program. Conversely, if future state-of-the-art batteries were available at this time, the demonstration phase of the act could be more broadly based.

However, considering the inexact projected development dates insofar as battery technology is concerned, and further considering the seriousness of the need of alternatives to the internal combustion engine, it would seem inappropriate to wait for battery technology to develop to the point that a more broadly based demonstration program could be embarked upon.

We are not qualified to predict the availability of a more advanced battery. As far as the demonstration program is concerned, we believe the industry is prepared to proceed immediately.

Answer to 10. e)

This answer is entwined in previous answers but specifically the data received concerning markets, life-cycle cost, efficiencies, criteria of performance and mission adaptability.

Answer to 10. f)

Obviously higher petroleum costs would have a favorable impact on the marketability of electric vehicles. Moreover, a petroleum shortage would have a larger impact, as would decreases in first cost prices of electric vehicles. It would be the objective of AM General through the efficiencies of increased manufacturing levels, and efficiencies in purchasing due to greater manufacturing levels, to bring the initial cost of electric vehicles nearer the initial cost of internal combustion engine vehicles. I feel that only through a continuing evaluation of the electric vehicle market which the demonstration phase of the Bill encompasses can we look for these efficiencies.

The questionnaire provided us jumps from Question 10 to Question 14, therefore, I shall next respond to Question 14.

Question #14

Should H.R. 5470 include, as an independent phase, hybrid vehicles suitable for long distance travel; what type of hybrid systems would benefit from a Government-sponsored demonstration program and what is the time frame.

Answer

The first recorded hybrid vehicle introduced in 1916 was a car powered by a battery and an internal combustion engine.

More recently proposed power plants for hybrids have included fuel cells, Stirling, steam, Wankel, stratified charge, diesel, and conventional internal combustion engines and gas turbines. Energy storage devices have included batteries, flywheels, compressed gases and thermo storage in molten salt. Most of these concepts use electric motors for vehicle propulsion; some use tandem or parallel power flows from the engine and electric motor through a single drive system. Interest in hybrids has paralleled interest in electric vehicles.

However, I feel hybrid vehicles have two major disadvantages. They present their owners with maintenance and repair costs for both engine and the energy storage device and the manufacturing cost, even on a mass production basis, can be expected to be higher than those of electric vehicles or internal combustion engine vehicles because of their design complexity. I see no part for the hybrid in the program.

Question #15

Should we include a rental, cooperative or leasing component in the program. An analogy to that of the Witkar in Amsterdam.

Answer

I do not recommend a Witkar-like program because of the following reasons:

1) The state of mass transit in the U. S. is not developed to a point that a Witkar-type demonstration program could be successfully demonstrated.

2) Witkar-type vehicles do not present nearly as viable an opportunity for the successful demonstration of electric vehicles in this country as does the light commercial van whose vehicle mission more closely parallels the performance specifications and range of the present state-of-the-art electric vehicle.

I do recommend the inclusion in the program of rental and/or leasing opportunities and incentives. The opportunity to lease or rent an electric vehicle will have a direct favorable impact on the marketability of electric vehicles. The opportunity to rent or lease vehicles will be attractive to all sizes of business concerns who wish to use capital for investments in other areas and will also make electric vehicles more accessible to small and low capital businesses.

Question #16

Just how severe is the problem of "mix" of E-V's with ICE's from a safety viewpoint for demonstration vehicles?

Answer

There should be no safety problem concerning the mix of internal combustion engine vehicles and electric vehicles if the mission of the demonstration vehicles suitably fits the capability of electric vehicles in today's state-of-the-art.

Obviously electric vehicles and internal combustion engines would not mix on the freeways. Electric vehicles should not be on the freeways because of their inherent low, by comparison, top speed capability. Electric vehicles and internal combustion engine vehicles have no safety problem mixing in surface street areas in either urban or suburban locations.

Question #17

Please identify the large utility whose fleet was discussed on page four of your testimony.

Answer

The fleet was that of AT&T.

Question #18

Please provide details on the time and cost involved in tooling, retraining, etc. in bringing your electric vehicle assembly line into production?

Answer

Let me restate Item 2 of my letter to you dated July 23 having to do with my testimony on June 4, 1975. Item 2 was the order of magnitude of investment necessary to manufacture the AM General Electruck.

AM General facilitized and tooled one of our plants in South Bend for approximately $6 million to build the unique Postal Service 1/4-ton, gasoline powered delivery vehicle. That investment was to manufacture on a one-shift basis up to 120 units per day. The aforementioned investment was for the manufacturing process only and does not include the investment in land or buildings.

Because the AM General Electruck is so uniquely similar to our gasoline powered vehicle, additional investment in tooling to build the electric vehicle was in the area of $1 million. It is for this reason, the size of the additional investment to build electric vehicles, that allowed AM General to sell its electric vehicle to the Postal Service, through the competitive bid process, for approximately $600 less per unit than the next lowest bid.

It is the unique similarity of our two vehicles that allows us to build these two units concurrently on the same assembly line. If that were not the case, the magnitude of our investment tobuild electric vehicles would approximate the combination of the $6 million and $1 million for a single shift capacity of 100 to 120 units. The total $7 million would not take into account escalations in cost that would be prevalent in today's marketplace.

Training to accomplish the manufacturing process involving the Electruck was a relatively simple program because of the similarity of our two vehicles. The in-plant training program lasted five weeks, which was roughly the equivalent of 10,000 direct man hours. The cost of the training program was in a magnitude of approximately $150,000.

Mr. Brown. Our next witness is Mr. A. Forbes Crawford, president of Jet Industries, Ltd., New York.

Mr. Crawford has also had very substantial experience in the electric vehicle industry. He has prepared some excellent testimony. We welcome you here this morning.

STATEMENT OF A. FORBES CRAWFORD, PRESIDENT, JET INDUSTRIES, LTD., NEW YORK; ACCOMPANIED BY W. L. BALES, EXECUTIVE VICE PRESIDENT, JET INDUSTRIES

Mr. Crawford. Thank you, Mr. Chairman. With me is Mr. W. L. Bales, executive vice president of Jet Industries, and one of our principal shareholders.

Mr. Brown. Do you wish to have your prepared testimony inserted in the record at this point?

Mr. Crawford. Yes, Mr. Chairman.

Mr. Brown. The entire testimony, including the attached exhibits, will be included in the record at this point. This constitutes an excellent summary of the entire industry.

[The complete prepared statement, including exhibits, of A. Forbes Crawford is as follows:]

A. FORBES CRAWFORD

PRESIDENT & DIRECTOR: Jet Industries, Ltd. (Dela.) & (B. C., Canada); Forbes International, Ltd. Previously he was President of a U. S. Truck Manufacturing Co. and a Tractor Manufacturing Co. In addition, he has been associated with the Investment and Commercial Banking business. Also with automotive & truck business in China and the U. K.

Statement - Wednesday June 3, 1975 by A. Forbes Crawford, President of Jet Industries, Ltd. to Subcommittee on Research, Development and Demonstration Act of 1975 (H.R. 5470)

ULTIMATE ELECTRIC VEHICLE

Mr. Chairman & Gentlemen:

The Commerce Dept. of a large University was asked to make a feasibility study of Electric vehicles potential. The staff first of all made an analysis of commercial vehicle use--that is:--daily mileage and so on--with large representative samples of commercial vehicle users in a metropolitan area. And the second thing they did was a fairly complex study of commercial purchaser preference and basically concluded that:

ELECTRIC VEHICLES THAT WERE AVAILABLE WERE LACKING IN TWO RESPECTS:

1. THE HIGH FIRST COST.
2. THE LIMITED RANGE

THE ANALYSIS SHOWED THAT IF EITHER ONE OF THESE FACTORS AND NOT NECESSARILY BOTH OF THEM, COULD BE SIGNIFICANTLY IMPROVED: -- THAT IS, IF THE PRICE COULD BE BROUGHT DOWN OR IF THE RANGE WERE INCREASED THERE WOULD BE A VERY SIGNIFICANT MARKET IMMEDIATELY.

The study was made without knowledge of our vehicle's performance and price. When the utility company that had asked for the study, acquainted themselves with our vehicle they placed an order for what I believe is the largest number of electric vehicles of one make bought by any utility company in North America:--Five to be exact.

OUR MAIN PRODUCTION VEHICLE GOES 45 MPH and 100 MILES PER BATTERY CHARGE. The retail price is $4,800. It is a light delivery or service vehicle which can be used as a small station wagon carrying three passengers besides the driver.

The following comparative figures were taken from various publications on Electric vehicles:

ELECTRIC VEHICLE STATISTICS

Manufacturer	Battronic	Otis	AMC*	JET
Miles per hour	30	45	33	45
Miles per battery charge	40	50	20	100
Volts	112	96	--	84
Weight lbs.	6,000	3,800	3,690	1,934
Payload	1,000	500	700	700
Wheelbase	94 1/2"	96"	81"	68.2"
Overall Length	145"	138"	136"	117"
Overall Width	78"	65"	70.62"	51"
Cargo Space	140 cu.ft.	70 cu.ft.	50 cu.ft.	90 cu.ft.
RETAIL PRICE	$16,330	$8,500	$5,598	$4,100-$4,800**

*American Motors Jeep **Lowest price is for MINITRUK---Highest for ELECTRA VAN

The EVI sold 50 units of Battronic Vehicles to Public Utilities for testing.

I recommend that Congress should set performance standards similar to ours: 45 MPH - 100 miles to a battery charge, for vehicles not exceeding 2,000 lbs. weight with batteries and various other standards for different weight & payload characteristics.

Japan's Industrial, Science and Technology Agency has earmarked $10 million for a five-year program. An agency spokesman says the first performance goals, a speed of 50 m.p.h. and a range of 124 miles between charges,were "completely achieved" and improvements are under way.

The Argonne National Laboratory in the U.S. estimates in the longer term that there could be as many as 1.8 million electrical vehicles on U.S. roads by the year 2000, requiring only 0.9% of the electricity generated in the U.S. The laboratory thinks that within five years a battery five times more powerful than the current lead battery will be on the market, giving a 100-mile no-recharge radius to the small electrical vehicle, which compares favorably with some small gasoline-fueled cars now marketed.

Now I would like to tell you how we arrived at our performance figures:

Myself and my partner W. L. Bales have been associated with the electric battery and I/C powered small vehicle business, probably as long as anyone present.

In addition, as individuals (and I'm not speaking of corporations) we probably have more of our own money invested in electric vehicle development than anyone present.

Many of you may know that many years ago when Ford Motor Co. decided to become interested in automobile racing, spending millions of dollars through their engineering staffs without the success they had hoped to attain. The company made a deal with one of the best "Cut and Fit" engineers in the race car business, Carroll Shelby. From Then on Ford was very successful in the race field.

I like to think that, my partner, Bill Bales, is to The Electric Vehicle business as Carroll Shelby was to the race car business in the U.S.

Mr. Bales Manufactured many thousand of 3 & 4 wheel golf cart and industrial Electric Vehicles in the late 50's and early 60's until a large company bought his company out.

He has experimented and worked with many different innovations that have been and are being tried in the Electric vehicle field.

1. Electric motors on each rear wheel.

2. Combination of Internal Combustion and electric battery powered drive.

3. Converting conventional American Trucks to Electric Battery Power

4. Converting conventional American Automobiles to Electric Battery Power.

In the early 60's we recognized a need for conserving fossil fuel and were partners in a small private truck manufacturing company that had developed a small AMERICAN MADE GASOLINE POWERED VEHICLE TO FILL THE MARKET subsequently filled by ONLY FOREIGN MADE GASOLINE POWERED VEHICLES:--DATSUN, TOYOTA, MAZDA, FORD COURIER AND CHEVROLET LUV PICKUPS.

In the late sixties we were developing an electric powered version of the aforementioned small van. It does perform along with the average of similar vehicles now on the market:-- 30 MPH 50 miles per charge.

HOWEVER, even before the energy crisis of 1973 we believed that it was necessary to develop a performance of 50 miles per hour and 100 miles per charge to have a commercially acceptable vehicle.

Fifteen years ago we had previously been through the exercise of using golf cart components:--suspensions, frames, steerings and etc. in trying to reach the commercially acceptable electric vehicle, with larger electric motors, controls and batteries, these would not hold up.

Previous attempts to convert U.S. made Automobiles and Trucks to Electric Battery Power have been self defeating. Because of the initial weight of the frame, suspensions, steering, wheels, tires, body and etc.:--large electric motors, controls and batteries have been needed to move the vehicles before you even put loads in them.

We still have molds for making fiber glass bodies of our previous small truck which we have converted to electric battery power. There are two reasons why we do not plan to use them:--1. They are too heavy for our targets of weight. 2. Petro chemicals used in making fiber glass objects would further deplete available fossil fuel ingredients. In addition to our present planned production vehicle, we have designed a frame and body of aluminum for our four wheel steered vehicle, and are making a prototype of larger van with as much aluminum as is possible to use-- in order to attain maximum performance.

Rather than go into the long period of organizing production of all the components needed for the entire vehicle, we decided to try to find a small vehicle in high production somewhere in the world. We first bought some light weight Japanese I/C automobiles (not sold in the U. S.) but on which there is a lot of experimentation in Japan. When we converted these to electric battery power, we were at first exhilarated because we we were reaching our goals of performance. But alas, after considerable road testing they couldn't stand up to the extra weight of larger motors, controls and batteries.

We then had a small commerical van manufactured to our specifications. With some beefed up suspension we attained our goals in Dec. 1973. Subsequently we had the stronger suspension and other amenities such as sliding doors included in a newer model, which is on display here. We have reached our goals of 45 MPH and 100 Miles per battery charge. This brings me to the main thrust of my message to you gentlemen.

TO BE REALISTIC one must examine the history of small I/C vehicles after World War II. It wasn't until Volkswagons, Fiats, Renaults, Austins, and other foreign made cars begain to penatrate the U. S. market to a substantial figure that U. S. manufacturers started taking the small cars seriously. WHAT DID THEY DO? Instead of producing small cars in the U. S., they started bringing in cars made by their foreign subsidiaries, and are still doing it. In addition, a good number of U. S. produced compact cars contain many components imported from the manufacturer's foreign subsidiary.

When Datsun & Toyota sales of pickups begain to show a market for such vehicles, no U. S. Manufacturer has started to make them (other than our aborted effort) and Ford imports the Courier Pickup and Chevrolet the Luv Pickup.

I am certain that the intent of the bill is to accelerate the manufacture and growth of electric vehicles as expeditiously as possible. To do this, would perhaps mean giving priority to vehicles designed to carry that average 350 lb. load which a Chrysler engineer said was the average for Pickups in the U.S. Our vehicle has a 700 lb. pay load. U.S. Automobile Manufacturers will not go into production of a new model vehicle unless they see 40,000 units per year. Maybe 20,000 if it is a big profit item. I would like to make the following suggestions for consideration by the committee:

1. Scratch the condition in the Bill that provides for purchasing several thousand electric Vehicles made from American Automobile Company Chassises.

2. Provide inducements that would encourage the same companies and all U.S. manufacturers to aim for the targets similar to ours, by importing light weight but strong components for which responsible foreign companies have already spent untold millions of dollars dev eloping and using in light weight sub-mini compact vehicles, until U. S. manufacturers can produce them economically.

3. Exemption of electric vehicles from the NHTSA Safety Act for a period of ten years (requiring them to conform only to the previous safety requirements--before the act)

The bill was to provide for the purchase of the Converted American Made automobiles because the chassis met NHTSA safety standards. I don't believe that should be a significant factor in considering the bill. Just recently, more men were sacrificed to rescue a ship from Cambodia than will be killed in the electric vehicles for several years of the exemption period. This is mainly because of the reasonably limited acceleration and speeds conformed to by electric vehicles which will result in better safety records than I/C vehicles with all of their safety equipment. We have found that LIGHT WEIGHT IS THE KEY TO REACHING HOPED FOR GOALS. So extra heavy bumpers could penalize performance.

4. That the bill provide that ERDA or whatever agency is to handle the funds, be authorized to guarantee loans for a qualified manufacturer immediately the bill is passed by both houses of Congress and approved by the President even though the funds may not be available until 1976. In other words, the agency could make future commitments for the funds which it knows will be available.

5. That ERDA or wnatever agency:--immediately order vehicles from various manufacturers so that production can be accelerated immediately. The manufacturers may then be able to finance on the orders and guarantees.

I shall mention in closing that on a one day advertisement in the Wall St. Journal Eastern and SW divisions for dealers requiring at least a $6,000 deposit, we had over two hundred applications. In a cold turkey survey by telephone of established automobile dealers in the New York area --40% indicated a desire to handle our vehicles if demonstrations would verify our performances.

I see no necessity for the U. S. Government to spend large sums of money for types of vehicles which cannot come up to performance standards already attainable.

In this respect, I will just review a few statistics for you. Between the Battronic MINIVAN and our ELECTRAVAN OR MINITRUK.

	Battronic	Jet	Percent of Battronic
Weight	6,400 lbs.	1,934 lbs.	30%
Price	$16,331	$4,800	29%
Payload	1,000 lbs.	700 lbs.	70%
Cubic Feet Cap.	140 Cu. Ft.	90 Cu. Ft.	64%
Miles Per Battery Chge.	50 Miles	100 Miles	200%

I apologize if I have misquoted the other company's figures because they were derived from publications. But those are not too far off and should give you some figures to consider.

A. Forbes Crawford

BIOGRAPHICAL SKETCH

JET INDUSTRIES, LTD.

C303 - 230 Park Ave.
New York City, N. Y.
10017

Jet Industries, Ltd. is a Delaware Corp. organized for the manufacture of electric battery powered and other vehicles. Its products consist of a small ELECTRAVAN with conventional steering and a similar sized MINITRUK with a four wheel steer for convenient parking. The latter vehicle also has a gasoline powered version attaining 40 MPG. In addition, they are developing a larger all aluminum electric van (except for running gear). Production facilities are in Texas and B. C., Canada.

The principals of the company are:

A. Forbes Crawford, President--who is also President of a Canadian Co. of the same name and Forbes International, Ltd. of Canada. Previously he was President of a Truck manufacturing Company and a Tractor Manufacturing Company. In addition he has been associated with the Investment and Commercial Banking business, as well as having interests in other manufacturing businesses.

W. L. Bales, Executive Vice-President--is also President of Bales Engineering Co. of Texas, and a major shareholder in a number of private businesses. Previously, he has been the chief executive, founder, and a major shareholder in a Truck manufacturing Company, Electric Golf Cart & Industrial Vehicle manufacturing Company, and Snowmobile manufacturing company.

ELECTRIC VEHICLE

"BREAKTHROUGH"

JET INDUSTRIES has engineered what it believes is a "BREAKTHROUGH" in Electric vehicle design with its current models of HIGH PERFORMANCE, LIGHT WEIGHT, RUGGED AND FLEET FOOTED PRODUCTS.

In predecessor companies the principals of JET INDUSTRIES had engineered and produced many thousands of three & four wheel electric industrial vehicles and golf carts. In addition, they had headed companies manufacturing tractors, snowmobiles and gasoline powered trucks. For many years they had been experimenting with the conversion of the trucks to electric battery power with reasonably satisfactory results.

When the energy crisis of 1973 erupted, efforts were concentrated on up dating the engineering and design work on electric vehicles for better performance. It was concluded that the major problem of the electric vehicle industry was a matter of weight versus available energy. By endeavoring to convert existing production trucks to electric power, too much of the energy was expended moving the vehicle, the weight of which had pyramided because of the need of larger electric motors, controls and batteries. On the lower end of the spectrum, golf cart components-- suspensions, steering, frames and etc. were not adequate for larger motors, controls and batteries to attain performance goals of loads, speed and distance per charge for satisfactory commercial use.

Jet Industries used Automotive and Aircraft techniques to develop new light commercial and passenger vehicles which in their opinion, have substantially attained the goals needed for a successful commercial application. The Company has developed two very utilitarian types in this field:

1. A station wagon-van with very finished body, interior and workman ship with conventional steering, multiple doors by driver's compartment, sides and rear, called ELECTRA-VAN.

2. A very Rugged strictly commercial type of Van with attractive appearance. It has four wheel steer (known as scissor-enabling it to park in congested parking space without having to back in), called MINITRUK.

JET's VEHICLE STATISTICS

Miles Per Hour 40 - 55 Miles per Battery Charge 75 - 100
(Dependent on gearing required for level or hilly terrain)

Retail Price ELECTRA VAN $ 4800* MINITRUK on Request

*Includes Southwind heater - not shown on demonstrater
Plus one twelve volt battery for auxiliaries

DEMONSTRATOR WILL BE IN MID TOWN FOR NEXT WEEK. Phone 212-689-9470 for appointment. Movie of four wheel steer MINITRUK is also available.

JET INDUSTRIES, LTD.

Suite C 303
230 Park Avenue
New York City,N.Y. 10017
212-689-9470

1141 West 6th St.
Austin, Texas 78703
512-263-2568 or 264-1814

314-850 Hasting St.
Vancouver 1, B.C.
604-688-6278

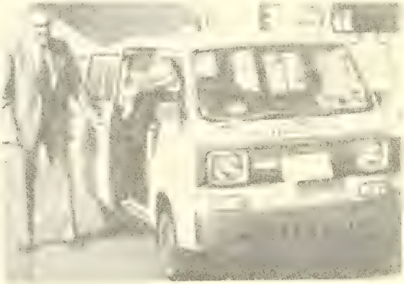
JET INDUSTRIES, LTD.
PRODUCTS
SPECIFICATIONS

MINITRUK		ELECTRA-VAN
Electric or Gasoline Power Four Wheel Steer		Electric Power Only Conventional Steer
120"	Length	117.9"
56	Width	51
57	Height	63
72	Wheel Base	68.2
7	Road Clearance	7.3
70	Cargo Bed Length	71.8
52	" " Width	46.7
46	" " Inter. Height	49
1800 Lbs.	Curb Weight-Elec.	1814 Lbs.
1450 "	" " Gasoline	----
2500 "	Gross "	2500 "
2 Std.	Seat Capacity (Opt.)	2 Std.
72 Volt SCR	Electric System	72 Volt SCR
7.5 HP @ 3200	" Motor	7.5 HP @ 3200
25 HP	Intermittent	25 HP
110 or 220V 6-10 hr. rate	Charger	Same as MINITRUK
Ball & Joint	Steering	Rack & Pinion
4-Wheel Independent	Suspension	4-Wheel Independent
5.20 - 10 Tubeless	Wheels & Tires	5.00 - 10 Four Ply
Disc - All 4 wheels	Brakes	Drums all wheels
54 HP @ 4800 RPM	Gasoline Engine	-------
Automatic 3 Speed	Transmission Gasoline	-------
45 MPH	Speed Electric	45 MPH
100 Miles	.Per Battery Charge	100 Miles
65 MPH	Gas. Engine Powered	-------
40 Miles Per Gal.	" " "	-------

BODY & FRAME

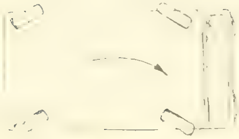
Aluminum - 2 Front & 1 Rear Door:- Standard (other opt.) MINITRUK has scissor steer for easy parking as standard equipt.

All Steel - 2 Front, 2 Sliding Side & 1 Rear Standard Conventional steering only.



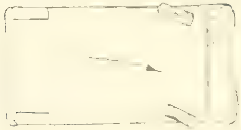
MINITRUK

Scissor Steer



ELECTRA-VAN

Convential Steer



LEFT:
Top - Both MINITRUK & ELECTRA-VAN are 3 ft. shorter than VW Beetle. But have same floor area as Datsun pickup
Bottom- Chassis of gasoline powered MINITRUK - showing scissor steer.

RIGHT: (Elec. system same in both vans)
Top - Battery cover shown. Comes carpet covered in station wagon version.
Middle: - 12 Six Volt Batteries = 72 V.
Bottom: - Showing controls and motor.

To File
Phone conversation

ULTIMATE ELECTRIC VEHICLE

Yesterday, [illegible] Hargreaves, Manager of the Public Service Department of the British Columbia Hydro Electric & Power Authority in Vancouver informed me that they had hired the [illegible] Department of the University of B.C. to do a study for them. The study [illegible] made an analysis of [illegible] vehicle use, that is daily [illegible] with large representative [illegible] of commercial vehicle users in the [illegible] area. And the [illegible] they did was a fairly complex study of [illegible] preference and [illegible] concluded that

ELECTRIC VEHICLES THAT WERE AVAILABLE WERE LACKING IN TWO RESPECTS:

1. THE HIGH FIRST COST. 2. THE LIMITED RANGE

THE ANALYSIS [illegible] THAT IF EITHER ONE OF THESE FACTORS AND NOT NECESSARILY BOTH [illegible] SIGNIFICANTLY IMPROVED -- THAT IS, IF THE PRICE COULD BE BROUGHT [illegible] IF THE RANGE WAS INCREASED THERE WOULD BE A VERY SIGNIFICANT MARKET IMMEDIATELY.

[illegible] Hargreaves the [illegible] for battery charge [illegible] Austin, Texas [illegible] Washington, D.C.

As [illegible] from the figures below which were developed from published literature [illegible]

ELECTRIC VEHICLE STATISTICS

Characteristic	Battronic	[illegible]	AM.*	[illegible]
Miles per hour	30	4[illegible]	33	45
Miles per battery charge	40	50	2[illegible]	10[illegible]
Volts	11[illegible]	90	--	84
Weight lbs	6,[illegible]	3,800	3,690	1,934
Payload	1,000	500	700	700
Wheelbase	94 1/2	96"	81"	68.2"
Overall length	14[illegible]	138	136"	11[illegible]"
Overall width	78	[illegible]	70.62"	51"
Cargo space	140 cu ft	7[illegible] cu. ft.	51 cu. ft	[illegible] cu. ft.
RETAIL PRICE	$16,330	$8,[illegible]	$5,548	$4,[illegible]-$4,800**

* American Motors Jeep **Lowest price is for MINITRUK-- Highest for ELECTRA VAN

The EVI [illegible] the Battronic to 50 Public utility figures for testing.

A. Forbes Crawford

---

western union Mailgram

A. FORBES CRAWFORD
FORBES INTERNATIONAL, LTD.
[illegible] PARK AVE. NYC 10017

WE [illegible] ORDER FIVE ELECTRA VAN UNITS AT A PRICE OF $ 4,800 EACH FOB [illegible] TAXES AND DUTIES, SUBJECT TO YOUR DEMONSTRATION [illegible] THAT THEY MEET SAFETY CONDITIONS REQUIRED FOR [illegible] APPROVAL IN COUNTRY OF MANUFACTURE BY OUR [illegible] WILL VISIT YOUR PLANT AS NEEDED [illegible] SEPTEMBER 13, 197[illegible] SECOND AND THIRD UNITS BY [illegible] AND FOURTH AND FIFTH BY NOVEMBER 1[illegible], 197[illegible] [illegible] WILL FOLLOW

[illegible] CHAIRMAN
[illegible] HYDRO & POWER AUTHORITY
VANCOUVER [illegible] CANADA

[illegible] Power [illegible]
[illegible] Rectifiers

D-C, Inc.

[illegible]
P[illegible] 817-[illegible]
Ft. Worth, Texas [illegible]

March 1[illegible], 1975

TEST REPORT
ELECTRA VAN WB [illegible]

Beginning in January 1975 and through March [illegible], 1975, the following test was made by our firm on this vehicle. These tests were made entirely in Texas, one being on a run of [illegible] miles along the Texas coast and the rest over a designated area of Fort Worth, Texas. This area consisted of a circle of streets which was a total of [illegible] miles and covered [illegible] streets [illegible] averaged [illegible] were [illegible] and speeds were from [illegible] to 40 m.p.h. This was done [illegible] five days with an average of [illegible] miles per day.

On the [illegible] highway run, the unit was transported [illegible] Texas and a straight run at 30-40 miles per hour was made [illegible] was done at the upper range of the [illegible] and the unit was run [illegible] the batteries were completely 'down'. The unit had run over a [illegible] for [illegible] 2 miles.

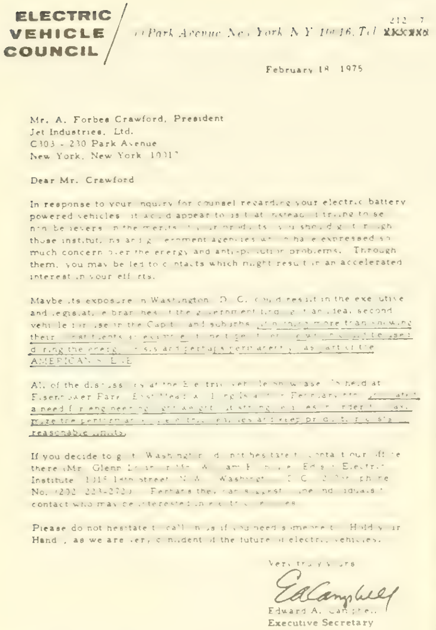
MPH	AMPS	Volts Average
[illegible]	[illegible]-20	[illegible]
[illegible]-18	[illegible]2-40	24
19-[illegible]	41-75	58
31-40	76-207	8[illegible]

During high torque periods, and this was usually as the unit accelerated 'across the batteries', a maximum of 20[illegible] amps was experienced but as the unit achieved speed, it would run at top speed and pull about 88-[illegible] amps. Tires were standard - 500-1[illegible] 4 ply inflated to 35 lbs all around. The independent suspension is excellent and with driver and passenger the unit seems to be perfectly balanced. There is no noticeable [illegible] and the unit turns corners and brakes much better than the writer could believe. On the city driving test, the batteries were about 60% discharged at the end of the run, and full recharge was achieved in ten hours with the on board charger. The 12 volt battery which handles lights, horn, directional signals, etc. is charged with a separate charger on board that receives its current from the same source when the main charger is turned on. The gross vehicle weight in all tests was 2,[illegible] lbs. Acceleration test was made on three different days and the 0-[illegible] average was 12 seconds.

Controls on this unit consisted of a key ignition switch to turn the unit 'on', a forward, neutral, reverse, mounted in the center console. Acceleration is with a standard foot accelerator. A standard hand parking brake is mounted in the center next to the F-N-R control. The battery manufacturer stated that the batteries should last from 700-[illegible] recharge cycles. The unit tested did not have a removable pack, but another vehicle not running was checked and one man [illegible] the batteries in [illegible] minutes. Battery weight is 920 lbs. Vehicle weight is [illegible] lbs. making a total of 1,994.

Very truly yours,

Ernest [illegible]
Ernest [illegible]



ELECTRIC
VEHICLE
COUNCIL

[illegible] Park Avenue New York N.Y. 10016, Tel. 212 7[illegible] XXXXXX

February 18, 1975

Mr. A. Forbes Crawford, President
Jet Industries, Ltd.
C303 - 230 Park Avenue
New York, New York 10017

Dear Mr. Crawford

In response to your inquiry for counsel regarding your electric battery powered vehicles, it would appear to us that instead of trying to sell non-believers on the merits of your products, you should go through those institutions and government agencies who have expressed so much concern over the energy and anti-pollution problems. Through them, you may be led to contacts which might result in an accelerated interest in your efforts.

Maybe its exposure in Washington, D. C. could result in the executive and legislative branches of the government finding it an ideal second vehicle for use in the Capitol and suburbs, [illegible] more than showing their [illegible] an example [illegible] could be used during the energy crisis and perhaps permanently, as part of the AMERICAN [illegible].

All of the discussions at the Electric Vehicle Showcase '75 held at Eisenhower Park, East Meadow, Long Island in February [illegible] a need for engineering light weight [illegible] vehicles in order to [illegible] the performance [illegible] vehicles and keep [illegible] reasonable units.

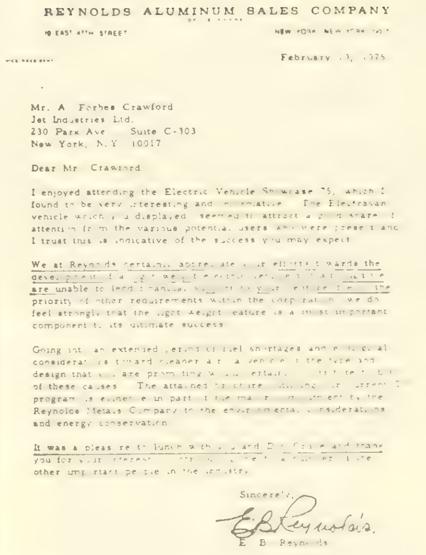
If you decide to go to Washington, do not hesitate to contact our office there (Mr. Glenn [illegible] or Mr. William [illegible]), Edison Electric Institute, 101[illegible] 14th Street, N.W., Washington, D.C. [illegible] phone No. (202) 223-2720). Perhaps they can suggest some individuals to contact who may be interested in electric vehicles.

Please do not hesitate to call on us if you need someone to "Hold your Hand", as we are very confident of the future of electric vehicles.

Very truly yours,

EdCampbell

Edward A. Campbell
Executive Secretary



REYNOLDS ALUMINUM SALES COMPANY
[illegible]

19 EAST 47TH STREET
NEW YORK, NEW YORK [illegible]

VICE PRESIDENT

February [illegible], 1975

Mr. A. Forbes Crawford
Jet Industries Ltd.
230 Park Ave. Suite C-303
New York, N.Y. 10017

Dear Mr. Crawford

I enjoyed attending the Electric Vehicle Showcase 75, which I found to be very interesting and informative. The Electravan vehicle which you displayed seemed to attract a good share of attention from the various potential users who were present and I trust this is indicative of the success you may expect.

We at Reynolds certainly appreciate your efforts towards the development of a light weight electric vehicle and that while we are unable to lend financial support to your venture due to the priority of other requirements within the corporation, we do feel strongly that the light weight feature is a most important component to its ultimate success.

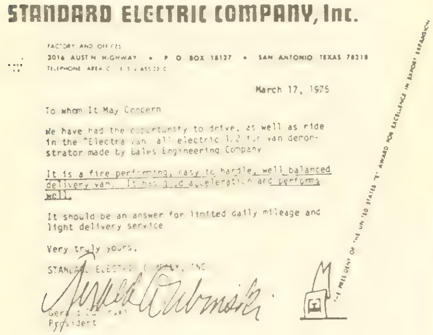
Going into an extended period of fuel shortages and ecological considerations toward cleaner air, a vehicle of the type and design that you are promoting would certainly contribute to both of these causes. The attached brochure outlining our current [illegible] program is evidence in part of the major commitment by the Reynolds Metals Company to the environmental considerations and energy conservation.

It was a pleasure to lunch with you and Dr. Crane and thank you for your interest [illegible] a number of the other important people in the industry.

Sincerely,

EBReynolds

E. B. Reynolds



STANDARD ELECTRIC COMPANY, Inc.

FACTORY AND OFFICES
3016 AUSTIN HIGHWAY • P. O. BOX 18137 • SAN ANTONIO, TEXAS 78218
TELEPHONE AREA C[illegible]

THE PRESIDENT OF THE UNITED STATES "E" AWARD FOR EXCELLENCE IN EXPORT EXPANSION

March 17, 1975

To whom It May Concern

We have had the opportunity to drive, as well as ride in the "Electra Van" all electric 1/2 ton van demonstrator made by Bales Engineering Company.

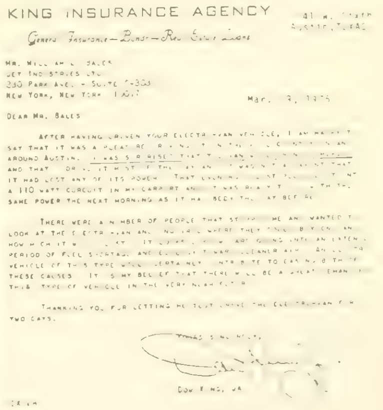
It is a fine performing, easy to handle, well balanced delivery van. It has good acceleration and performs well.

It should be an answer for limited daily mileage and light delivery service.

Very truly yours,

STANDARD ELECTRIC COMPANY, INC.

Gerald [illegible]
President



KING INSURANCE AGENCY
General Insurance—Bonds—Real Estate Loans

41 W. [illegible]
AUSTIN, TEXAS

MR. WILLIAM [illegible] BALES
JET INDUSTRIES LTD.
230 PARK AVE. - SUITE C-303
NEW YORK, NEW YORK 10017

MAR. [illegible], 1975

DEAR MR. BALES

AFTER HAVING DRIVEN YOUR ELECTRA-VAN VEHICLE, I AM HAPPY TO SAY THAT IT WAS A PLEASURE [illegible] AROUND AUSTIN. I WAS SURPRISED THAT [illegible] AND THAT [illegible] MOST OF THE DAY AND [illegible] WAS NOT [illegible] THAT IT HAD LOST ANY OF ITS POWER. THAT EVENING I JUST [illegible] A 110 WATT CIRCUIT IN MY CARPORT AND IT WAS READY TO [illegible] WITH THE SAME POWER THE NEXT MORNING AS IT HAD BEEN THE DAY BEFORE.

THERE WERE A NUMBER OF PEOPLE THAT STOPPED ME AND WANTED TO LOOK AT THE ELECTRA-VAN AND INQUIRE WHERE THEY COULD BUY ONE AND HOW MUCH IT WOULD COST. IT LOOKS LIKE WE ARE GOING INTO AN EXTENDED PERIOD OF FUEL SHORTAGE AND [illegible] TOWARD CLEANER AIR AND [illegible] VEHICLE OF THIS TYPE WILL CERTAINLY CONTRIBUTE TO EACH OF THESE CAUSES. IT IS MY BELIEF THAT THERE WILL BE A GREAT DEMAND FOR THIS TYPE OF VEHICLE IN THE VERY NEAR FUTURE.

THANKING YOU FOR LETTING ME TEST DRIVE THE ELECTRA-VAN FOR TWO DAYS.

YOURS SINCERELY,

DON KING, JR

DK:[illegible]

Alternatives to the Conventional Engine

ELECTRIC CARS—SET FOR ANOTHER COMEBACK?

BY DANIEL M. COSTIGAN

This article is a good SUMMARY OF ELECTRIC VEHICLE DEVELOPMENT plagiarized by JET INDUSTRIES, LTD. from ROAD & TRACK for your convenience. The author was not acquainted with JET's products at time of article. Nor did JET's ELECTRAVAN & MINITRUK PICTURES (on page) appear in original article.

One of the more predictable side effects of the recent energy crunch has been the re-emergence of that perennial transportation standby, the electric automobile. Evidently, when it appeared to have been trounced into extinction by its more lively combustion-powered rival a half-century ago, the indestructible electric had merely gone into temporary exile It has been returning sporadically ever since to haunt its detractors.

There were occasional rumblings of an electric-car revival during World War II when gasoline had become scarce, and again in the late 1950s when smog and noise had reached menacing proportions in several American cities. But the really big push was not to come until the great electric-car revival of the 1960s, with Ford and General Motors announcing dramatic breakthroughs in the development of modern electric passenger cars. That was late in 1966. By the spring of the following year all the big carmakers were busily developing electric cars, and a dozen or more prototypes had been built and demonstrated

But after a couple of years of considerable fanfare, during which it looked for a while as if the end was near for the venerable internal-combustion engine, the climate suddenly changed and the electric car quietly retreated into its cocoon to await the next resurrecting crisis. As things turned out it hadn't long to wait. That crisis came with the Arab oil embargo late in 1973.

Two unfortunate things happen every time the electric car makes one of its periodic reappearances. First, people blithely forget that the electric is not the all-inclusive answer to fuel shortages and air pollution that it purports to be, and have to be repeatedly re-educated to the fact that you don't get something for nothing. Second, the concept of vehicles powered by electrical energy somehow invariably manages to pass itself off as something new and revolutionary.

On the first point there is, of course, something to be said for the centralization of energy conversion—for the positive effects it can have on conversion efficiency and the control of air pollution. To begin with, not all electricity is produced by the burning of fossil fuels. In the U.S. the figure is about 85 percent, part of the remaining 15 percent being produced by water power at dams. Of the 85 percent nearly half is produced by the burning of coal, which is still fairly plentiful. Moreover, despite opposition by ecologists the number of nuclear powerplants has continued to grow, their power-generating capacity having nearly doubled between the end of 1971 and the end of 1972 (from 8687 to about 16,000 megawatts).

As for conversion efficiency, Federal Power Commission statistics indicate that it takes roughly a pint of fuel to produce one kilowatt-hour of electricity at the source, and automotive engineers have determined that approximately a third of a kwh of energy would be required at the motor output of a practical electric passenger car for each mile traveled. (By "practical" I mean a car with a range of about 100 mi on a full charge and a speed capability of 50 to 60 mph.)

If at this point you are somewhat confused about the relationship of commercial power to battery power, just remember that in effect the electric car's battery is merely a device for temporarily storing power from an outside source. Where that source happens to be commercial power, and it normally is, the big loss in the process is in transmission of the power from the generator to the point of use. There is approximately a 50-percent cumulative transmission loss from power-station output to car-motor output within the charge-discharge cycle But strictly from the standpoint of oil consumption this would be canceled by the fact that oil accounts for only about half the commercial electricity produced. Thus we have, in our electric, a vehicle that yields some 24 mi of travel per gallon of oil consumed which isn't bad

But then the availability of an electric with the capabilities described, and bearing a "reasonable" price tag, assumes some significant breakthroughs in the development of new, more efficient battery systems. Using existing technology such a car would have to be as heavy and expensive as a pair of standard limousines

It bears mentioning, incidentally, that the 24-mpg estimate is if anything a conservative one that can be boosted according to whose statistics and philosophies you are willing to accept. Efficiency estimates will naturally vary; and it can be argued, for example, that the use of battery chargers overnight during normally idle hours will take up some of the slack in power-generating capacity, thereby making the whole electric utility operation more efficient.

But what of pollution? Doesn't one power-generating facility do as much polluting as a whole horde of combustion-powered vehicles? Obviously it does. In fact, GM engineers have determined that, in grams per mile of electric-car travel, pollutant emissions from powerplants burning fossil fuels would actually be greater than those produced by individual combustion-powered cars meeting 1975 emission control standards. In fairness, it must be said that the proponents of electric propulsion have been able to produce equally plausible findings to the contrary Moreover, we must not overlook the fact that, being centralized, the pollution produced by powerplants should be somewhat easier to control

As for the second point—the popular misconception of the electric vehicle as something relatively new and modern—one need only look in any reasonably comprehensive text on the history of the automobile to see how very old the concept is. Records show that an electrified carriage was built in Scotland as early as the late 1830s, and that even before the beginning of the present century battery-driven vehicles had set world speed records on at least two occasions

Going a bit beyond the realm of the private car, the first electrically powered rail car was built and operated by a Vermont blacksmith as early as 1834 (it ran on batteries). And in 1886 two Englishmen, Campbell and Ash, built the first

TOP RIGHT

Jet Industries - ELECTRAVAN 45 MPH 100 Range Utility Commercial vehicle & stationwagon

BOTTOM RIGHT

Jet Industries - MINITRUCK - 4 wheel steer Elec. or Gasoline powered (40 M. per Gal.).

battery-powered submarine, which they named the Nautilus Both inventions started trends, the culminations of which are still very much in evidence today

By the end of the first decade of this century electric-powered land vehicles, both the rail and road variety, had become a common sight all over the civilized world. Both were somewhat restricted in their range of travel. The rail variety, which now ran on distributed power rather than batteries, was confined pretty much to intracity trolleys and short-haul interurban passenger runs, whereas the battery-operated road variety was strictly a town car.

The electric automobile of this period was all the vogue among the well-to-do, especially with ladies who wanted to do their own driving. It was quiet, clean, dependable, and simple and inexpensive to operate. Unfortunately its lacy virtues were no match for the sheer masculinity of its combustion-powered counterpart, in whose dust it eventually perished (temporarily, as it turned out).

The real reason for the eclipse was the comparative inefficiency of the electric car's motor. A fuel engine of comparable size and weight (including the fuel tank) not only had more power and a considerably greater range on a single fueling but could be refueled and on its way again in a matter of minutes. The electric began to flag after about 25 mi. and then had to sip fresh nourishment from a charger for hours on end. The demise was complete when the fledgling car-service industry had grown responsive to popular preference and geared itself exclusively to the combustion car.

But even excluding the rail variety, electric vehicles in general have never really left us. In 1968 there were more than 40,000 in use on public roads throughout the world, most of them short-haul delivery vans and most of those in England. I recall that electric delivery trucks, most if not all of obviously early vintage, were still a fairly common sight on the streets of New York City as recently as the 1950s.

Then there are the on-premises industrial vehicles, such as forklift trucks, that have been in more or less general use in factories and warehouses since the early 1940s, and of which there are now at least 100,000 in daily operation in the U.S. alone. Offsetting the austere ruggedness of these chunky workhorses are a growing variety of sleek little electric personnel carriers, of which the golf cart is perhaps most familiar

But despite its continued existence little was done to advance the technology of the electric car until the big pollution scare of the 1960s. The major automobile manufacturers took their cue from the statements of several influential public officials (including at least one high-ranking Cabinet officer) to the effect that the combustion-powered car was a menace to public health. With so much re-inventing of the wheel these days, the developments that came out of that brief but exceptionally productive episode are worth reviewing.

Ford's bid was a sodium-sulfur battery with 15 times the storage capacity of conventional lead-acid batteries. GM's was a dual offering: a newly developed battery with somewhat less storage capacity than Ford's and a fuel cell of the same basic type that had been used successfully as the electric power supply for the Gemini and Apollo spacecraft. GM immediately followed through with two prototype vehicles, each employing one of the two proposed power systems.

There were shortcomings, of course. The high storage capacity of Ford's prototype sodium-sulfur cell was obtainable only when→

ELECTRIC SYSTEM SAME ON BOTH VEHICLES.
Bateries (920 lbs.) 84 VOLTS on URBAN MODELS (total weight 1934 lbs.)
45 MPH - 100 Miles per CHARGE.
Batteries (540 lbs.) 54 VOLTS on IN-PLANT MODELS (total weight 1414 lbs.)
25 MPH - 65 Miles per CHARGE.

the cell was heated to a temperature hot enough to broil steak (about 570° F). GM's silver-zinc battery was costly and short-lived, and its fuel cell was not only bulky and complex in its then-existing form but required three chemical reservoirs, two of which had to be replenished at 125-mi intervals. Other designs involved the use of precious (and therefore costly) metals and highly reactive (and therefore potentially hazardous) combinations of metals and gases.

Among the more promising new battery designs unveiled, from an initial cost standpoint, was the zinc-air, on which at least five big electrical manufacturers had already spent considerable development effort over a period of several years. It was built of inexpensive materials and was durable, but it offered a gain in capacity of only about seven times that of lead-acid batteries (as opposed to 100-times and greater gains cited for some of the more exotic batteries then under development). And like GM's fuel cell it required the pumping of a fluid electrolyte through its cells while in use.

As for the vehicles in this 1960s renaissance, probably the most imaginative was American Motors' Amitron, a sleek, teardrop-shape coupe whose 50-mph cruising speed and 150-mi (maximum) range put it well within the realm of practicality as a commuting car. Its comparatively lightweight (200 lb) battery supply consisted of a set of special lithium-nickel fluoride batteries for cruising and a separate set of nickel-cadmium batteries for acceleration. The car's range was stretched somewhat by a regenerative braking feature that converted the drive motor to a charging generator whenever brakes were applied.

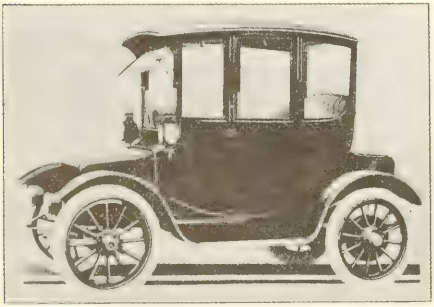
But, as with all of the other moderately efficient electrics that had been developed so far, the attractiveness of the Amitron was dulled by the size of the price tag that would have had to be put on these cars were they to be made commercially available. The batteries alone, though less expensive than some of the other special propulsion batteries that had been developed recently, would still cost more than the price of a whole engine for a combustion-powered luxury car (the special batteries for GM's experimental Electrovair II cost $15,000 in 1967).

Despite all the obstacles, the people closest to the revival—automobile and battery-company executives and researchers—had remained optimistic about the electric car's possibilities. Dr Victor Wouk, who had directed the development of the batteries used in the American Motors prototypes, believed that we were now "closer than ever" to the time when electric vehicles could promise performance "as good as, if not better than, an ordinary gasoline car." And Leonard Crossland, British Ford's Assistant Managing Director, had noted that his company regarded its diminutive Comuta prototype as merely "a step in our program to develop a commercially practical electric car."

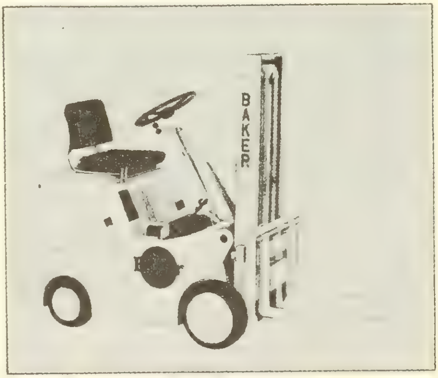
To the designer of electric passenger cars, weight and recharge time become critical considerations. The battery efficiency of passenger vehicles capable of cruising on open roads at reasonable speeds and for reasonable distances is measured in watt-hours per pound. About the highest rating to date of new-design batteries that have actually been road tested is 100, which gives the car a maximum range of about 150 mi before it has to take a three- to five-hour breather for recharging.

One way around these problems would be to provide electric cars for intracity use only, on a rental basis. There have been a number of formal proposals along these lines. Another way, not quite so easy to implement, would be to adopt a plan put forth by Cornell Aeronautical Laboratory in the 1960s (or a similar one advanced around the same time by Alden Self-Transit Systems of Westboro, Massachusetts), in which an electric car would run on batteries locally and on distributed power via an electrified guideway for long hauls. While operating in the guideway mode, the car's batteries would be recharged so that it would be ready for its next local trip on its own power. In 1967 the Cornell group foresaw their Urbmobile concept becoming a practical reality by the year 2000.

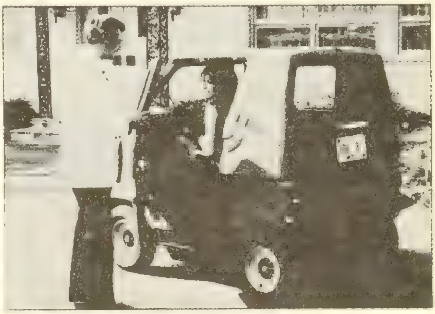
Still another way to circumvent some of the problems inherent in pure electric propulsion would be to effect a compromise in the form of a hybrid fuel-electric car that would be combustion-powered on the open road and battery-powered in the cities. During the late 1960s and early '70s GM, Ford and the U.S. Army investigated the practicality of just such a car. GM had in fact built and tested an imaginative prototype hybrid.



An early electric town car by Baker, circa 1910, was quiet and clean.



The modern-day Baker Electric: a forklift truck rather than a town car



The Elcar is currently available in two models: the 1000, with a top speed of 25 mph and a range of 35-50 miles; and the 2000, which will do 35 mph and travel 25-35 miles between its battery-recharge stops dual-powered by an AC electric motor and a low-emission Stirling external combustion engine it co-developed with the Philips Company of Holland. If government intervention in the interest of public health should ever force industry's hand through a banning of combustion-powered cars from cities, the fuel-electric hybrid car is certainly as plausible a compromise as anyone could ask for.

Perhaps you are wondering what became of all these apparently earnest efforts to provide the public with a refreshing new breed of car. Unfortunately (or perhaps fortunately, depending on your point of view) by early 1969 a general change in the political and economic climate had acted to dilute whatever incentive there might have been to pursue a serious automotive revolution. When things recently began to look ripe for a new electric-car revival I queried some of those who had contributed to the advances made in the late 1960s.

GM responded with a terse statement to the effect that it is continuing to do research in the area, but that ". . . the problems—both technical and economical—are still quite formidable." Of the various technical reports they provided, the latest is dated January 1971. The subject is air pollution, but the report stresses the negative aspects of electric cars in general and concludes that it will be 20 years or more before they become a valid replacement for combustion-powered cars.

Most interesting of GM's more recent developments is the XEP experimental car, which operates from an improved lead-acid battery for acceleration and a zinc-air battery for cruising. It can do 60 mph and can go as far as 150 mi on a charge at half that speed. But it has one big drawback: recharging the zinc-air batteries requires replacement of not only the electrolyte (in six separate units) but also all 300 zinc plates.

Ford replied that it has continued its development of the sodium-sulfur battery, concentrating on fabrication of the solid ceramic electrolyte that is a key component of the system. A contract with the National Science Foundation has provided a welcome boost to this effort. But, though optimistic about the battery's potential, Dr W. D. Compton of Ford's Research Center in Dearborn admitted in a recent talk that ". . . we have a long way to go to make this a commercial system."

Chrysler, who had operated at the fringes of the developmental thrust of the 1960s, failed to respond to a similar query for updated information.

American Motors reported that it has no current projects relating to electric cars. But, as it turns out, this is not entirely true. An AMC subsidiary, AM General Corporation (producer of the Jeep), was recently awarded a $2 million-dollar contract to produce battery-powered delivery vans for the U.S. Postal Service. This current activity, however, has no connection with the Amitron project of the 1960s, which according to the AMC spokesman was suspended when it was decided that the car had ". . . not come up to original expectations."

American Motor's sleek little Amitron electric could do 50 mph and go 150 miles on a single charge. It featured an electric braking system and had separate batteries for its cruising and acceleration power supplies.

Gulton Industries, who had developed the Amitron's batteries, notes that it had suspended its electric-vehicle research and development program in March of 1971, although it continues to provide special batteries and chargers to the transportation industry. In a recent interim report to stockholders it speaks of the energy crisis mainly in terms of the ill effects it could have on the company's operations.

But as any perceptive observer will acknowledge, the conditions for a revival of interest in electric cars have never been better. And despite the apparent skepticism of the U.S. automobile industry the signs of an impending revival are everywhere.

The Japanese, for example, who recognize as well as anyone the dangers of building a civilization on a vital resource they don't possess, have a number of short-range electrics under development as evidenced at the 1973 Tokyo Automobile Show. The picture is much the same in Europe, where in Holland a computer-controlled intracity rent-a-car scheme has begun operation in Amsterdam, its fleet of midget electrics getting quick-charged from overhead feeders placed strategically around the city; and where at least three of Germany's automotive giants (Volkswagen, Daimler-Benz and Bosch) have become active in electric propulsion in varying degrees. In England, Enfield Automotive already has in production a two-passenger electric with a 50-mi range, and in Italy Zagato, the noted prototype builder, is currently mass-producing its popular Zele two-seater at the rate of 30 to 50 a day. The Zele will be marketed in the U.S. as the Elcar, a name that may ring a bell for some car buffs.

Here in the U.S., electric-car development has by no means ceased. The action has merely shifted (for the time being) from the big carmakers to a host of relatively obscure firms, notably Sebring-Vanguard, a Florida golf cart maker; Battronic Trucks, the electric-vehicle subsidiary of a big custom truck-body firm in Boyertown, Pennsylvania; Electromotion, of Bedford, Massachusetts; Die Mesh Corporation of Pelham, New York; and two Michigan firms: EVI, Incorporated of Sterling Heights (a maker of adult pedal cars) and Electric Fuel Propulsion of Ferndale. Some of these—Electric Fuel Propulsion, for example—lean toward the electrification of standard compact cars like AMC's Gremlin. Others design and build the electrics completely from scratch.

In addition, some larger firms outside the auto industry, notably Otis Elevator, have committed sizable funds to the development and/or production of electric vehicles. Otis alone is currently offering a variety of 14 different battery-powered vehicles include a 50-passenger bus. Going in a slightly different direction, Lockheed of San Francisco is among those developing vehicles in which an electric motor first revs up a flywheel of very special design and then becomes a flywheel-driven generator which powers the vehicle's drive motor. All told there are some 40 makers of on-the-road electric cars, trucks and buses throughout the world, some of them having been in the business for several years.

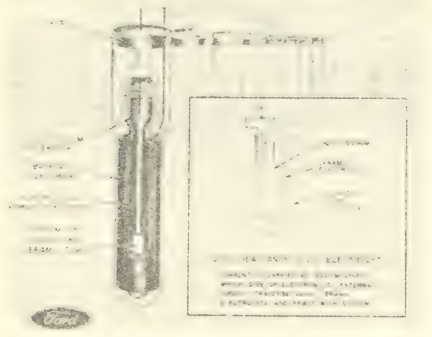
PHOTO BY DEAN BATCHELOR

Ford's Autolite Lead Wedge, a different sort of electric car, established a land speed record for battery-powered cars in 1968: 138.862 mph.

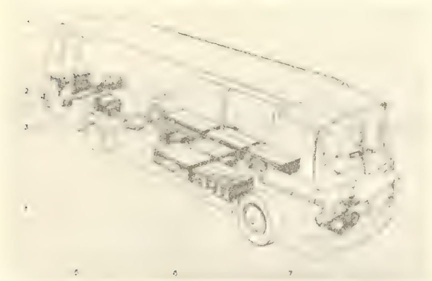
The present emphasis is on mini-electric passenger runabouts and short-haul utility and delivery vans. Here in the U.S. Sebring-Vanguard has already begun an anticipated production run of some 2500 Citicars, which have a top speed of about 30 mph, a range of about 50 mi on a charge and a suggested retail price of a little over $2000. As for the vans, there are strong indications that operators of large short-haul fleets like the Postal Service are looking at electric propulsion with more than passing interest. About 40 electric mail vans of various makes are currently in regular use in at least four American cities (Allentown, Pennsylvania, Cupertino, California, Lowell, Massachusetts; and Stockton, California), and the Postal Service has already placed an order for 350 additional units. According to reliable forecasts this number could easily bloom to several thousand by the end of 1975.

Although they may cost more than their combustion-engine equivalents (typically twice the price), there are definite long-term advantages in electric vehicles for government and commercial users. Most significant is the greater longevity and lower maintenance requirements. But not to be minimized is an advantage unique to the electrics: the fact that in stop-and-go city traffic they consume "fuel" only while in motion.

For these same reasons another class of electric vehicle, the battery-powered passenger bus, is receiving increasing attention these days—mostly from the transportation administrators of major cities. Similarly, electric utilities (hard-pressed though some of them are to meet present power demands) are evidently looking to the future by starting now to promote the use of battery-powered vehicles, at least within their own internal operations (by meter readers, for example).



Ford's sodium-sulfur battery was just one of many exotic new power sources developed during the electric-car revolution of the late 1960s.

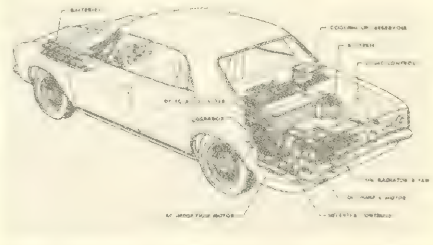


Mercedes-Benz's diesel-electric bus of 1969. A small sound-insulated diesel engine (1) drives a generator, which charges five large lead-acid batteries (5). A single large electric traction motor (3) drives the rear wheels; blower (2) cools it. The batteries are cooled by another blower with its duct (7); (4) and (6) are parts of the vehicle's control system.

Technologically, the current crop of electrics has nothing resembling the sophisticated complexity of the prototypes developed by the auto industry in the late 1960s. The prevailing technology is typified in the vans and small buses produced by Battronic Trucks. All five basic vehicles in the company's product line, ranging from a truncated Minivan (500- to 1000-lb payload) to a sleek 25-passenger bus, use essentially the same basic electro-mechanical design: a GE 112-volt series-wound DC traction motor operated from two banks of more or less conventional lead-acid batteries. Though the batteries and motor are of the latest design within their class, the principal departure from traditional electric-vehicle technology is the use of new solid-state electronic control techniques.

The jerky starts and uneven speed transitions characteristic of early electric vehicles are eliminated in the modern version through use of an electronic "chopper" circuit consisting of transistors, capacitors and silicon-controlled rectifiers. The idea is to run the drive motor on pulsating rather than steady current so that its speed can be controlled by lengthening or shortening the pulses rather than by wasting some of the current in resistive ballast. The technique has been in use in forklifts and similar vehicles for several years.

Does this return to a simpler technology mean that the highly sophisticated advances made by the U.S. auto industry in the 1960s are down the drain? Not at all. Obviously, the prototypes produced to date would be economically and technically impractical to put into production, and Detroit can't be expected to advance the technology much farther until there's been a showing by the motoring public that it genuinely wants and is willing to pay for such a radical new departure in automobiles.



Despite its innovations, GM's Electrovair had a range of only 80 miles between recharges and required a set of extremely expensive batteries.

What is significant about the present reliance on the simpler, traditional approach is that it makes possible the production and marketing of electric vehicles at prices people can afford.

Logically, anyone who had to rise at 4 a.m. to take his place in a gas line two or three times a week last winter is a prospective customer for an electric car. If the same thing happens again (and there are many who predict it will) we can expect to start seeing electric vehicles in increasing numbers on highways and on the streets of our towns. At first they will be of the simple, low-speed, short-range variety. But as the market develops the big carmakers will be watching for their cue to put something more luxurious into production.

That something will most likely be some form of fuel-electric hybrid at first. But with the mounting pressures for exploration of new technological avenues, it is just possible that we may see some form of competitive all-electric passenger vehicle—one that can be used for reasonable distances at more or less normal speeds on the open road—go into volume production within the next three to four years.

Mr. Crawford. On the material that we submitted, we pointed out, at the start, sir, about the feasibility study made by the Commerce Department of a large university. Their conclusions were that the electric vehicles that were available were lacking in two respects—that is, before they knew about our performance.

Now, one of the problems was the high first cost. The second was the limited range.

I would like to mention on the high first cost factor that, yesterday, I was acquainted for the first time, with the estimated price of the sale of a converted American-made compact car, $12,000. That is a pretty high cost.

The limited range, Mr. Chairman, that is something that is a very important factor.

The Japanese Science and Technology Agency earmarked $10 million. They set performance goals of 50-mile-per-hour speed with a range of 124 miles between charges. We have attained 45 miles per hour and 100 miles per battery charge. We have had some vehicles geared to go 55 miles per hour. We felt that the vehicles should be confined strictly for urban use because of the limited range involved. We set—well, if we set them at 55 miles per hour, somebody might go on the highway with no place to plug in the charger at the time.

Now, because the vehicle is in that range, we have confined our philosophy to this. I will skip over a lot of the details in this because I assume that you have copies of this and it is being included in the record.

Mr. Brown. Yes.

Mr. Crawford. I am therefore recommending, and Mr. Bales agrees with me on this, that the performance standards should be set, such as the targets that we have. That is, for vehicles not exceeding a [illegible],000 pound weight with the batteries in them, and that other standards be set for different load categories.

Now, Mr. Chairman, there is a vehicle that is listed here that weighs 6,000 pounds. That was an original figure that we had given to us. Further on, this is shown as 6,400 pounds. Our vehicle weighs 1,934 pounds. Our vehicle itself: the body of the chassis and the suspension, the steering, and everything with the accessories, weighs less than the electric motor, the controls, and batteries. It is in this particular area that we are trying to emphasize the need for extreme lightweight vehicles, Mr. Chairman.

I have made various suggestions in the material that I have submitted here. I will not take up a lot of time now other than to say that one of the big problems is the lead time of the electrical components, the controls, motors—they are the biggest problem. We sort of figure that, maybe, there should be the need to have large companies have patents that are pooled with ERDA for use by other manufacturers in order to utilize those to expedite filling the need for electrical components; also, competition will bring the price of them down.

In our presentation, Mr. Chairman, we emphasized the need for following up what happened to the light internal combustion engine powered vehicles, where, after the war, Volkswagens, Renaults, and Fiats, penetrated the market. The big American companies were not interested until they became a significant factor. They did not start making them themselves. They started importing the models made by their foreign subsidiaries.

Even today, on some of the vehicles that they make as a compact vehicle in this country, they import components from some foreign subsidiaries.

As I mentioned, some big companies will not go into the manufacture of a vehicle unless they see 40,000 or more of them a year. They will sometimes do it with a special vehicle, like a four-wheel drive, which Ford did when they brought out their four-wheel drive small vehicle.

Now, Mr. Chairman, Mr. Bales is the real expert on this. He has made 35,000 three and four-wheel electric industrial vehicles and golf carts in the late fifties and in the early sixties. He and I were associated with a company that made a vehicle to fill the need that was filled by Datsun, Toyota, Mazda pick-ups and the like. We also went into updating the electric vehicle version of that vehicle.

When the energy crunch came, that vehicle was too heavy for us to meet the target that we had in mind. That is why we looked around for a small vehicle with high production. We first bought some small Japanese passenger cars. We converted them. We reached our goal, but they turned out at the time to be too lightweight. They were not rugged enough. We went on into the van construction.

The one that you gentlemen saw yesterday and that is parked in front today, that is what we decided on as a quick way to get into the electric vehicle numbers, because the people that we buy it from produced them in high numbers.

Mr. OTTINGER. The vehicle that you have here, is that your van?

Mr. CRAWFORD. Yes. It is imported from Japan. It was converted to electric battery power.

Mr. OTTINGER. Thank you.

Mr. CRAWFORD. Yes, sir.

Mr. BROWN. Will you yield?

Mr. OTTINGER. Yes.

Mr. BROWN. We welcome any comments that Mr. Bales may have that are based on your experience, or his. It seems that the unique feature that you have presented here in your vehicle is the lightweight and relatively strong construction. That is a very important aspect of an electric vehicle, to get the maximum performance from the batteries. If you would like to elaborate on that aspect of the vehicle at this time, you may do so. Also, the matter that you mentioned of exempting the vehicle from the safety requirements for a 10-year period you may comment on that. It may be significant, Mr. Bales.

Mr. BALES. Thank you, Mr. Chairman.

All of our problems in the past have been discussed earlier. It has been a matter of weight. The batteries weigh as much as the vehicle put together. We do not have anything better right now that is economically feasible.

At this time we have to consider replacing the lead acid battery. I think that this is where all of the research needs to go right now, getting a different type of battery which does not weigh as much as they do today.

Mr. Chairman, it is going to be possible, but I don't know how quick we can do this. This has been the problem all along with the electrics. The energy that we can store is not now sufficient to push actually the amount of weight. That is why we are limited here, especially in areas where we put the vehicle.

In my way of thinking, the flatter the country, sir, the better this will run. In our tests we found that we could go into a hilly area with multistops, but this cuts our performance with regard to this by about 50 percent. Well, when you have Miami, Houston, and places like that, or New York City, well, that is another very good one. These are the type of places that I would like to see the vehicle started.

We have worked 15 or 16 years on this type of light vehicle. When we go into the heavier vans, and I am no expert there, and I don't know anything about them; although, I do know, basically, what they are all about. I am describing the light weight vehicle. This is the largest vehicle that we have ever built. We have stayed with the smaller vehicles.

Now, du Pont and a lot of the big companies, they have large areas, such as 25,000 acres, and while there, we are not required to go on streets other than those involved in the company compound. This is the type of operation that we have worked in.

Mr. BROWN. Is that where most of your market is at this time?

Mr. CRAWFORD. Go ahead, Mr. Bales.

Mr. BALES. All of our markets now would be in the industrial field.

Mr. BROWN. Industrial?

Mr. BALES. Yes.

Mr. CRAWFORD. May I add something to that?

Mr. BALES. Go ahead.

Mr. BROWN. Mr. Crawford.

Mr. CRAWFORD. I think that there is a much bigger market than just the industrial field. There is such a demand by industrial users that most of our production would be taken up by industrial users quite rapidly.

As I mentioned in my memorandum, a 1-day ad in the New York—well, the Eastern and Southwestern edition of the Wall Street Journal, this brought over 200 replies. We put in there, that in order to make an application as a dealer, that one would have to put up some money. That was to keep high school kids from writing in to say that they wanted to be dealers at the time.

Now, Mr. Chairman, out of the 200 replies, maybe 40 percent would be qualified to be dealers. We made telephone surveys to other dealers. We did this in the New York metropolitan area. Out of 100 that were contacted by phone, about 40 percent said that they would be a dealer for the vehicle if the demonstration would confirm our performance figures. I don't think that there is any problem in selling vehicles to the public once they are produced.

Thank you, Mr. Chairman.

Mr. BROWN. Mr. Ottinger, at this time have you any questions?

Mr. OTTINGER. You are a Canadian manufacturer? Are you a U.S. citizen?

Mr. CRAWFORD. I am a U.S. citizen. We manufacture these in Texas. We have a Canadian company. I have sort of been living in Seattle or Vancouver. The vehicles, they are of American manufacture.

Mr. OTTINGER. You made an interesting suggestion: that is, that ERDA be allowed to guarantee loans, Mr. Crawford.

Mr. CRAWFORD. Yes.

Mr. OTTINGER. I take it that one of the major difficulties for many of the smaller companies is that involving the raising of capital to get into extensive production in which the guaranteed loan would assist you.

Mr. CRAWFORD. It would help very much. Today, any small manufacturer or small company, no matter how good their management and facilities are, or their product, if they start out as a new company, and if they go to a broker, the broker says that their investors could buy investments in going businesses at a discount. Why, then, should they buy into a new company?

I looked into the matter. I looked in the paper last night. There are still companies that are listed on the New York and American Stock Exchange where you can buy them at one times earnings. That is a pretty good bargain. They are companies that usually have existed for some time. Money is a big problem. I think that the loan guarantees may be something like the FHA or a Government structure, that this would be good. This would make it attractive for the lending institutions to put up the money. I think that this would facilitate matters, Mr. Chairman. We are not asking for grants. All that we want to do is to get money to accelerate the production. That is what we want.

I think that there are a lot of other small manufacturers in the same category.

Mr. OTTINGER. Getting back to my first question, you manufacture these in the United States. What is the reason for your first recommendation that, and I quote:

> Scratch the condition in the bill that provides for purchasing several thousand electric vehicles made from American automobile company chassis.

Mr. CRAWFORD. We import the body or the chassis from Japan in this case. If your big provision is to buy several thousand electric vehicles made on American automobile company chassis, and each cost $12,000, you will not have very many of them purchased before you have utilized all of the funds that you have appropriated. Personally, I don't see how people can pay that much money for an electric vehicle with this limited range when they can buy, probably, the most expensive American internal combustion powered car at that price.

Mr. OTTINGER. If you were required to meet the safety standards, what kind of performance would that imply?

Mr. CRAWFORD. I would say this, and Mr. Bales can supplement it. In this particular case, where we are buying a vehicle off the shelf in Japan, so to speak, they would have to change their production procedures to meet the American safety requirements. They are not far off now. Any time that you ask somebody to make a change, this requires, well, they have to throw this into a computer. Six months later they may say that they can't do it or they don't want to do it at the time.

Mr. OTTINGER. You do not have figures as to how much weight that this would add to the car and how much this would detract for the performance?

Mr. BALES. It would add approximately 250 pounds to our vehicle.

Mr. OTTINGER. Do you have now any idea what that would mean in terms of your performance?

Mr. BALES. Approximately 10 percent off.

Mr. OTTINGER. Ten?

Mr. BALES. Yes.

Mr. OTTINGER. Under ideal conditions it would be 90 miles instead of 100 on the charge?

Mr. CRAWFORD. It would cut down our payload.

Mr. OTTINGER. Thank you.

Mr. BROWN. You are importing the chassis from Japan. You are not importing the motors, wheels, or anything of that sort?

Mr. BALES. We did at first. We have to get the whole thing to begin with, but as the actual production went on, we cannot bring it in with the internal combustion engine—which we remove. The whole idea is to buy from the major manufacturers who supply this. We would be doing nothing but assembling components, basically, sir. We have tried the actual manufacturing, but until you go beyond 10,000 units, you cannot build them as cheaply as someone else building them can, such as other types of components. We are tooled up completely with another unit of the same size. Our cost would go way up if we had to use our own built chassis or bodies.

Mr. BROWN. Is that an aluminum type?

Mr. BALES. No, sir, it is all steel.

Mr. BROWN. Steel?

Mr. BALES. Yes, sir.

Mr. BROWN. Would there be any savings, or is it engineering feasible to use aluminum for this since it is lightweight, say?

Mr. BALES. Yes; we could probably take 17 percent of the weight off if we had decided to use aluminum. Right now we cannot draw some of the components in aluminum.

Mr. BROWN. I notice that you had a letter from Reynolds Aluminum expressing interest.

Mr. BALES. Yes.

Mr. BROWN. I thought that they saw a big market for the aluminum.

Mr. BALES. That is what we discussed at the time. We wanted to do it. We are using some aluminum underneath our motor carriers. We could knock out a substantial savings in weight.

Mr. CRAWFORD. We do have a prototype of our minitruck with an aluminum chassis and aluminum body. We can make this ourselves. It would be so much more expensive than doing this the way that we are doing it at present.

We are also making a prototype of a much larger type. We are making an aluminum chassis and body. Further along the line after we accumulate money, maybe we can come up with a lightweight larger electric vehicle.

Mr. BROWN. It would be greatly to the advantage of this country to be able to produce its own chassis at a cost or price that is comparable to those being produced in Japan.

Mr. BALES. Yes.

Mr. CRAWFORD. That is right.

Mr. BROWN. Do you think that this is an impossible goal, given sufficient volume, say, that we are into the tens of thousands of units? Is there any reason why we could not produce them on an assembly line over here at prices comparable to the Japanese prices, or is their labor rate and the other factors such that we could never hope to compete with them?

Mr. CRAWFORD. We could do that here. Chevrolet is coming out with a little vehicle called the Chevelle, which I think will be here next year. That is a submini vehicle. It might be like a small Honda or Austin. Ford is also planning a small vehicle. Whether they make it in this country or in a foreign factory, I don't know. The components would be available to utilize. If they make it in this country, we would try to buy components from them rather than to make them ourselves in this country.

Mr. BROWN. Well, gentlemen, I think that we will have to bring this session to a close.

We very much appreciate your testimony.

Mr. CRAWFORD. Thank you.

Mr. BALES. We are glad to be here.

Mr. BROWN. Mr. Crawford, I have found that you have a very large amount of useful information in your statement before the committee.

Mr. CRAWFORD. Thank you.

Mr. BROWN. We very much appreciate your cooperation. If we have further questions, I hope that we can send them to you in writing. If you can help us further we would certainly appreciate it.

Mr. CRAWFORD. Thank you very much for letting us present our viewpoint.

Mr. BROWN. It has been a pleasure.

[Answers to additional questions submitted to Mr. Crawford follow:]

JET INDUSTRIES LTD.

Mr. Thomas Moss
Committee on Science and Technology
U.S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. Moss:

Thank you for your courtesies to myself and associates during last week's hearings on the H.R. 5470 Electric Vehicle Bill. Attached are copies of letters I have written to several members of the committee. For the record, I would like to make the following comments regarding remarks made by some of the witnesses:

1. Too much emphasis was placed on BATTERY DEVELOPMENT. Many firms have been working on improvements for quite a number of years--in effect, already using U.S. funds through write-offs against income from their regular business.

2. The proponents of giving priority to RESEARCH AND DEVELOPMENT WILL DELAY ANY real penetration of the Electric Vehicle into markets as long as there are funds available for R & D which is the most profitable and less productive of FEDERAL FUNDS.

3. The suggestion to have a Federal Agency act as an agent for service and parts distribution is very unrealistic. The witness who suggested it has produced about 700 Vehicles(according to his statement) compared to tens of thousands between Mr. Bales and myself.

4. The mechanics of setting up the administration of purchasing and leasing electric vehicles would be an enormous task and very time consuming. I believe the intent of the act could be better served by channelling funds, guarantees and etc. into the hands of companies which have already spent their own money gambling on the future of the Electric Vehicle. Good old U.S. COMPETITION will make a quicker penetration into the market than the proposed method suggested by the bill.

5. Consideration should be directed toward providing a separate classification for Electric Vehicle under the Federal DOT Safety Regulations, as they are a separate type of vehicle designed for a more limited use in a more restricted area. For example electric vehicles are designed primarily for urban use at low speed and lower acceleration rates than I/C vehicles.

Passage of the bill in any form as proposed may be very important at this point for the Political impact it might have on the OPEC countries. The administration of the bill can take care of any compromises necessary to satisfy any opponents.

Hoping the foregoing is of some assistance, I am

Very truly yours,

A. Forbes Crawford

A. Forbes Crawford, President

July 18, 1975

RESPONSES TO QUESTIONS ON H. R. 5470

By JET INDUSTRIES, LTD.
A. Forbes Crawford, President

1. There is a definite role for the U. S. Government in aiding the development of the electric vehicle industry by:

   a. Guaranteeing loans for manufacturers.

   b. Making direct loans to manufacturers.

   c. Guaranteeing loans to leasing companies who buy from manufacturers.

   d. Allowing EVs to comply with Safety Standards set by States before NHTSA standards were made effective in 1966 or 1967. Since most EVs will be used for urban purposes, there will be no problem as Intrastate vehicles. Canada has same standards as U. S. on Federal level but if a Province will lincense an electric vehicle (or any new vehicle inovation) it can be used in that Province but cannot be sold in another Province. The same could apply in the U. S.

   e. Allow components to be imported for use in EVs to be duty free.

   f. Allow vehicles imported for conversion to EVs to be duty free.

   g. Possibly make loans or grants to cities to provide EV garages with power facilities for charging vehicles overnight. (In New York--for example--there is an average $8 per night or 24 parking fee in mid town areas--with need by garage operators to move vehicles around). A feasibility study in N.Y. indicates this could be biggest obstacle to use of EVs for commercial or private use in the Manhattan area. IT IS VERY SERIOUS. On street parking with possible charging meters could be an exercise of "Musical Chairs" with owners or drivers trying to find a convenient place to park--where there was a charging meter. IN ADDITION, VEHICLE VANDALISM is rampant. Same would be true with all large METROPOLITAN CITIES.

Large companies are not interested in new products. Practically all need existing capital for own purposes.

Small companies cannot attract venture capital because of bargains in stock of already proven companies. Neither can they borrow for venture capital purposes. There is plenty of experience and ability around to make the electric vehicle competitive if working capital funds were available. Potential ELECTRIC VEHICLE MANUFACTURERS can be found among Recreation Vehicle, golf & industrial Cart, and small truck manufacturers. Most of the products made by these companies are the assembly of purchased power trains, suspensions, frames (and complete chassises)--into bodies which they make. There is a lot of expertise and ability among these manufacturers, who have the facilities and personnel (some have the finances) to switch into ELECTRIC BATTERY POWERED VEHICLES at paces as fast as the supply of electric components become available.

The AERO SPACE CORP. of EL SEGUNDO, CALIFORNIA just received $117,000,000 from the U. S. AIR FORCE who had to get rid of that amount of money which was a surplus to their needs before new appropriations became available.

The PRINCIPALS of JET INDUSTRIES, LTD. will gladly set up a NEW CORPORATION to do the same for the Government on Electric vehicles. If CONGRESS could get the Administration to demand that the AIR FORCE instruct AERO SPACE CORP. to immediately divert some of the $117,000,000 to the NEW ELECTRIC VEHICLE CORP. REASEARCH COMPANY, it would:

1. Interest a large number of manufacturers--as mentioned above to consider manufacturing E-Vs
2. Develop accelerated availability of ELECTRIC COMPONENTS.
3. Develop sources of suspensions, steering, frames-both domestically and Foreign.
4. Handle the administration of procurement for the Government.

2. a. See Attached Schedule A

   b. The industry is limited by lack of investment and banking capital for new industry . In addition, NHTSA Safety Requirements impose engineering constraints on electric vehicles which do not have the acceleration or high speed of I/C vehicles. They should be in a special category like motorcycles and bicycles.

3. Best means of procurement:

   a. Low Capital companies will not be able to finance accepted bids without the assistance of government.

   b. Loan guarantees provisions will enable small companies to raise capital. This could be similar to SBA loans but on 100% basis through banks for production working capital only. Financing of plants and development work are non productive.

   c. There are probably no patent infringements to be concerned with since Electric Vehicles have been operating since the turn of the century. Delivery schedules or contract penalties could be a handicap for any company due to inconsistent deliveries of electrical components. The bill should include loan guarantees to companies manufacturing electric motors and controls; and new innovations of batteries (if approved by competent Federal experts).

   d. It would be preferable to confine purchase commitments to fixed numbers of vehicles in given price ranges--tied to performance goals of speed, range and load capacities.

   e. Large auto manufacturers costs would be higher than small companies until volumes of 20,000 or more could be produced by the large companies. Small companies can buy suspensions, steering units, and other running components on an O.E.M. basis from manufacturers of high volumes. Large companies could do the same but are not inclined to do so--vis-a-vis the growth of sales of small foreign cars in the

Schedule A

MARKET POTENTIAL

Fleet operators of light trucks having a gross vehicle weight of 10,000 lbs or under comprise the largest prospect for future market of Electric Vehicles. The following Motor Vehicle Manufacturers Association shows Light Truck sales in 1973:

Body Type	GVW - 6,000 lbs or Less
Pickup	1,218,062
General Utility	183,775
Panel	3,821
Van	232,063
Multistop	3,029
Total	1,640,210

The Light Truck Census (U.S. Department Commerce more clearly defines the Market Potential for Electric Vehicles:)

(Pickup, Panel Multistop, and Walk-in, 10,000 lb. GVW or less)

Number in Use	13,027,894
Number Used in Local Service	9,757,892
Type of Use (major users)	
Services	1,003,147
Wholesale/Retail	794,701
Utilities	325,697
Lease/Rental	62,466
Total Vehicles Used by Four Major Users	2,186,011

The designated number of vehicles used in local service are classified as those vehicles used for personal transportation and in agriculture, where typical operating procedures exceed EV capacity which leaves a total of 2,000,000 vehicles operated by major users in the field that EV vehicles would be applicable. Such as fleets of light pick-up, panel, multi-stop and walk-in vehicles. Government surveys as well as those conducted independently indicate that the present markets for EV's in this area could be over 1,000,000 vehicles, provided the vehicles were economical, capable of distant use and have a normal price range.

A. Feb. 1974 - University of Wisconsin Marketing Department shows the rate of penetration of Electric Vehicles on the auto market could be as follows:

1974	1%	4,000 Vehicles
1979	10%	145,000 Vehicles
1980	15%	246,000 Vehicles

B. The Argonne National Laboratory in the U.S. estimates in the longer term that there could be as many as 1.8 million electrical vehicles on U.S. roads by the year 2000, requiring only 0.9% of the electricity generated in the U.S. The laboratory thinks that within five times more powerful than the current lead battery will be on the market, giving a 100-mile no-recharge radius to the small electrical vehicle, whick compares favorably with some small gasoline fueled cars now marketed.

C. Jet has two vehicles that can attain a 100-mile range today and 45 MPH.

U. S. after World War II. It was not until volumes exceeded 10% of total U. S. production that U. S. Manufacturers started making them in the U. S. and then most of running gear was imported from their Foreign subsidiaries.

f. NHTSA Safety regulations do not allow the import of foreign complete vehicles (for conversion purposes) unless U. S. converter brings them into compliance within 90 days. Under the Safety Act, exemptions are allowed for up/2500 vehicles per year--up to 3 years. Some personell maintain that if the foreign manufacturer of origin produces more than 10,000 vehicles per year, that the vehicles are not allowed in under any circumstances. Electric Vehicles should be exempted for ten years from NHTSA safety regulations (but allowed to comply with individual States' licensing requirements existing before the 1966 NHTSA regulations became effective).

4. Consumer acceptance is good for vehicles with 45 mph and 100 miles per charge and priced under $5,000, with commercial payload of 500 lbs. or 4 passengers as a multi-purpose vehicle.

5. At present there appear to be no key institutional barriers in general.

6. Maintenance facilities will not be a problem but charging stations will definitely be a problem in large cities--refer to 1 (g) in the foregoing.

7. The acceleration of production of electric vehicles will result in small manufacturers buying components for different sized vehicles, or the vehicles (for conversion to electric battery power) from U. S. manufacturers on larger sized units and from their Foreign subsidiaries or other Foreign manufacturers. A removal of duty on the import of the components or small vehicles (for conversion) could result in large U. S. automotibile manufacturers accelerating their interest in Electric Vehicles.

8. Phase I should include FOREIGN CHASSISES because there no light weight ones available from U. S. automobile manufacturers--although their Foreign subsidiaries have some good light weight but strong chassises and vehicles that could be converted.

9. a. Electric vehicles are safer because of slower acceleration and top speed than I/C vehicles. Limited range on battery charges confine their perimeters of operation to urban use with speed not to exceed 45 miles per hour. There fewer fatal accidents in the city per volume of traffic compared to limited access highways (outside of cities and the thruways in the cities).

   b. There are no hydrogen fume problems on properly ventilated battery compartments. Most electric vehicle batteries are heavily built sturdy industrial types from which sulfuric acid spills would be minimized. In addition, they are covered completely so that any spills would only occur when covers were damaged.

10. a. & b. can be answered best by the Dept. of Transportation which has financed many projects in this connection, including the Morgantown electrified roadway for $60,000,000,the hearsay of which is not encouraging.

    c. We are not familar with current costs and effectiveness of Fuel cells. If nuclear regenerating units could be developed on a small safe scale--it would answer the fossil fuel problem. It is our understanding that present Fuel cells require replenishment of chemicals too frequently to be practicle for everyday use, at least for the present.

11. It is necessary to have a wide spectrum of practial use of electric vehicles in different climates, terrains, traffic patterns congestions and charging facilities--in order to determine technological needs. There may be certain areas of the country which are more conducive to the use of E-Vs than others.

    a. The grogram proposed by the bill could provide this but it is possible to expedite a penetration of the market by "band aid" to some of the early entrepenuers; providing funds for further development but especially production: ONE SOURCE COULD BE THE AERO SPACE CORP. which was forced to accept $117,000,000 of unspent funds form the U. S. Airforce--before the new budget was effective.

    b. The time frame is well within the possibilities of attaining the bills objectives--IF THE GOVERNMENT DEALS WITH SMALL BUSINESSES.

    c. There is no reason to delay the program pending developing of advanced batteries. The EPA already spent many millions in this area and the results are still:--advanced batteries are too costly. LEAD ACID batteries can do the job. The need is to concentrate on the engineering concept of Jet Industries:--build light weight but strong vehicles so battery energy is not wasted carrying heavy vehicle weight.

    d. All funds should be used for developing the technology of light weight but strong vehicles to use the existing LEAD ACID BATTERIES. Large Companies are using Government funds for developing advanced batteries in the form of tax write-offs as "RESEARCH & DEVELOPMENT" against income from main production items.

    e. The demonstration program could benefit from the use of today's LEAD ACID BATTERIES. Refer to c. & d. above.

    f. Jet Industries, Ltd. can produce, sell and make a profit under under present costs. Its market would increase in direct ratio to the decrease in ELECTRICAL COMPONENTS WHICH ARE HIGH IN RELATION TO CHASSIS COMPONENTS.

12. HYBRID SYSTEMS should not be included in the program of H. R. 5470. Jet Industries' Principals have tried that route 17 years ago. The vehicles are neither "FEAST" nor FOWL".

13. Guarantee of loans to qualified leasing companies would seem to be the most reasonable manner in which to approach that facet of consideration for the following reasons:

    1. The companies have the expertise, personnel and facilities.

    2. They would know how to intelligently structure rates and maintenance schedules.

14. JET's experience with its EV in urban traffic has been satisfactory. It is able to accelerate with the average flow of traffic up to 45 miles per hour and brake to a stop in an ordinary flow, or in emergency stops.

1975

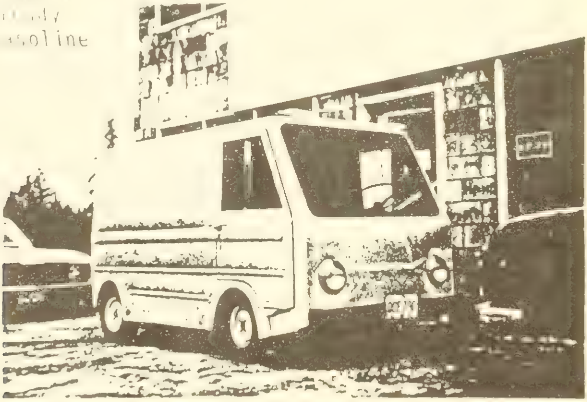
Top - ELECTRA VAN

Bottom - MINITRUK
(Four Wheel Steered)

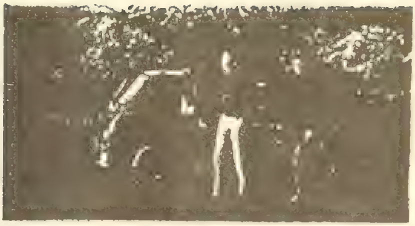
Mr. George Hargraves, manager of B.C. Hydro's public service department queries Mr. Crawford, president of Jet, about the amenities of the newest model of Jet's vehicle received from Japan for conversion to electric battery power. Mr. Hargreaves travelled to Austin, Texas, in February of this year to evaluate for B.C. Hydro an earlier prototype of the electric vehicle converted by Jet.

It took Jet 3 1/2 years to negotiate contract for parts for this vehicle, for delivery as is in Japan:--no variations considered. Now ready for conversion on production basis.

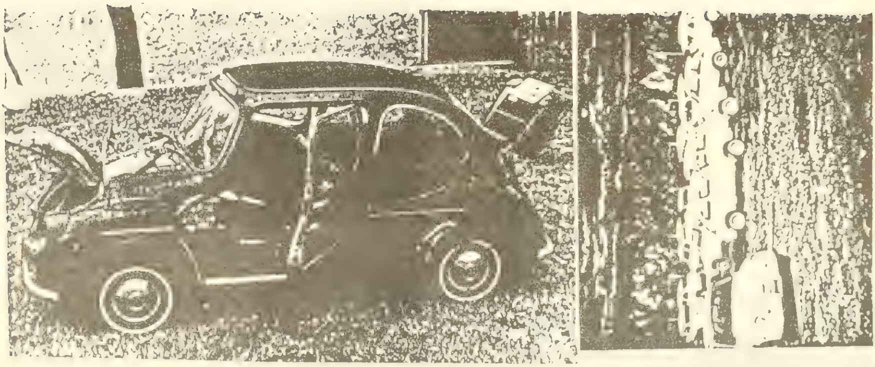
[illegible]
[illegible]
[illegible] Now ready
[illegible] with gasoline
[illegible] motor.



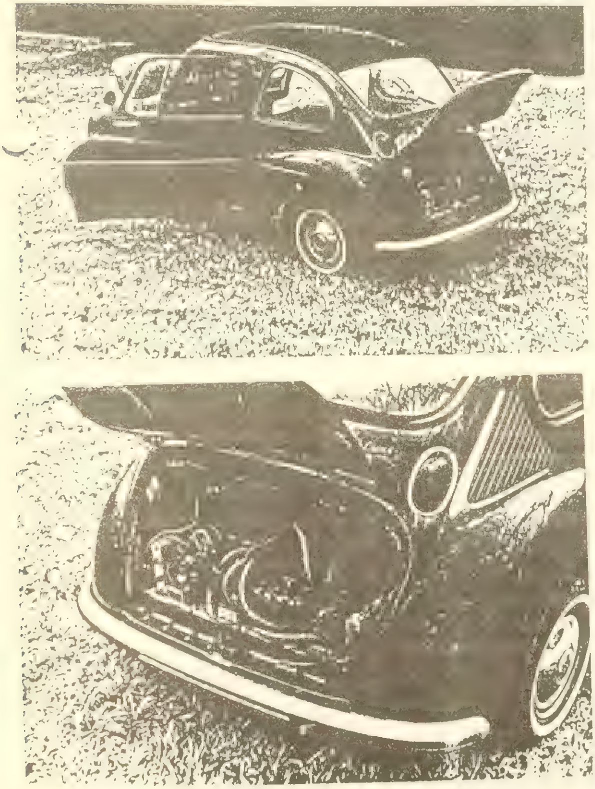
1974



This is earlier model of ELECTRA VAN.



This vehicle reached performance goals [illegible] conditions.



1973

Imported Chassis & Body proved to be light in suspension & steering strength to carry the pyramided weight from installation of heavier motor controls and batteries to reach targeted performance.

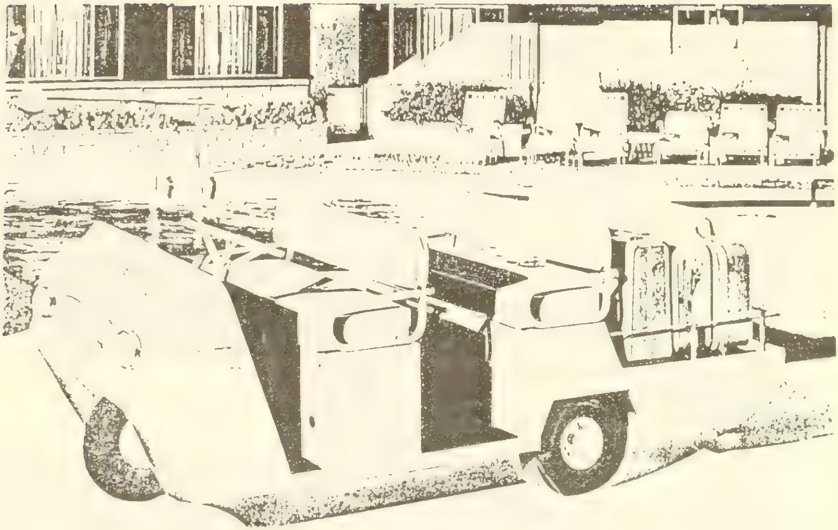
RESCREEN & SQUARE HALFTONES

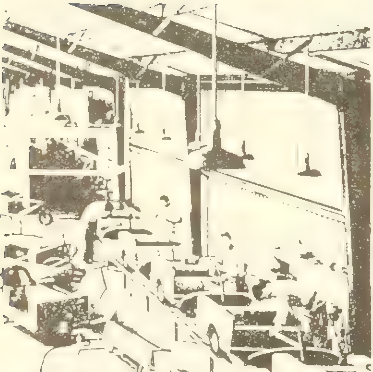
1968 - 1969
Gasoline

An electric powered version of this small van was made in 1972 but is too heavy to enable it to reach targets of 45 miles per hour and 100 per charge.

1964

Gasoline





Golf cart components are too light to use in commercially feasible vehicle--requireing heavier motor and batteries.

Late Early
1950s 1960s

Mr. Bales. I wish to thank the committee, also, for this opportunity.

Mr. Brown. The subcommittee meets again tomorrow morning at 9:30 a.m. We stand in recess until that time.

[Whereupon, at 10 a.m., the subcommittee recessed to reconvene at 9:30 a.m., the next day.]

ELECTRIC VEHICLE RESEARCH, DEVELOPMENT AND DEMONSTRATION ACT OF 1975

THURSDAY JUNE 5, 1975

House of Representatives,
Committee on Science and Technology,
Subcommittee on Energy Research,
Development and Demonstration,
Washington, D.C.

The subcommittee met, pursuant to adjournment, at 9:45 a.m., in room 2318, Rayburn House Office Building, Hon. Mike McCormack, chairman of the subcommittee, presiding.

Mr. McCormack. The committee will come to order, please.

Good morning.

Today marks our third day of hearings on H.R. 5470, the Electric Vehicle Research, Development, and Demonstration Act of 1975.

Certainly, the material presented during the last 2 days of hearings has been most beneficial to the members of the committee and staff in our deliberations on this bill, and I look forward to further information which will be developed by this morning's witnesses.

One point has become very clear during previous testimony. There is near unanimity that the goals of H.R. 5470 are of major importance, and that changing our personal transportation system to electric propulsion is vital if we are to continue to have a viable transportation system, one independent of our dwindling supplies of domestic or imported petroleum.

We have pinpointed, through these hearings, some of the key technical and socioeconomic problems that must be attacked in order to assure the effective development and commercialization of electric vehicles. We have also learned methods by which these problems have been and may be addressed. Information of this sort is extremely helpful in our efforts to develop the best legislation, and, following that, the best implementation program for accomplishing our common goal.

Our witnesses include a broad spectrum of expertise on the subject of electric propulsion, coming as they do from the academic and industrial communities.

Without wishing in any way to detract from our other distinguished witnesses, I would like to call special attention to our second witness today, The Electric Vehicle Council. We are extremely fortunate to have the outstanding interest and support of groups such as the Electric Vehicle Council and its members and associates. As was evident from the vehicles which this group displayed on the first day of our hearings, an enthusiastic and talented electric vehicle industry, although somewhat small, already exists, and this gives us added confidence for a successful program as proposed by the bill.

I would like to also comment that we have had a large number of requests from persons to testify which has been simply impossible to accommodate. For this we are truly sorry, and all we can do is to accept the written testimony and put it in the record.

I would like to, therefore, acknowledge at this time testimony from Elcar Corp. of Mr. Leon Shahnasarian, president, which will be inserted in the record along with the other testimony for today's hearing.

STATEMENT OF LEON G. SHAHNASARIAN, PRESIDENT, ELCAR CORP.

[The testimony of Mr. Leon G. Shahnasarian, Elcar Corp. follows:]

Testimony of Leon G. Shahnasarian, President, Elcar Corp.

Chairman McCormack and Members of the Subcommittee, we, the Elcar Corporation, appreciate this opportunity to submit our written testimony in support of proposed H.R. 5470, Electric Research, Development, and Demonstration Act.

My name is Leon Shahnasarian, President of the Elcar Corporation, and my associate accompanying me is Mr. Robert Culver, also of the Elcar Corporation. Our corporation is one of only two companies who are actually marketing nationally a typical commuter vehicle. We are so extremely pleased with the introduction of this bill, that we felt it was of great importance to bring two models of our Elcar Electric Car to Washington for display and to offer our assistance in the passing of this proposed legislation.

Elcar Corporation is an Indiana corporation, incorporated in June of 1974. We are the North American distributor of the Elcar Electric Car of Italian manufacturing origin. These vehicles are of low emission characteristics, featuring 35 m.p.h. top speeds, and approximately 35 miles driving range between recharges.

We now have one year of experience in marketing and consumer sales of our electric car, which confirms the actual society needs of low emission commuting vehicles that are not entirely dependent on available gasoline supplies and are basically pollution free.

Due to our past experience and the tremendous interest in these diversified means of transportation, we, the Elcar Corportion, have already developed our own American made version of the Elcar. Presently, we are proceeding to tool for the manufacture of our electric car which is specifically designed from the ground up as an electric vehicle. This vehicle will accommodate four passengers, can be used for light delivery service, is ideal for governmental agencies, and could comply to postal delivery specifications. The maximum speed of this vehicle is 38 to 40 m.p.h., with approximately a 40 mile driving range. A unique characteristic of our electric car is the slide-out battery tray which can readily be exchanged for another fully charged battery tray in a matter of minutes (about the same time required to fill a conventional car's gas tank). This allows for a greater driving range. A prime feature of this automobile will be the economical price structure, $2995.00 to $3995.00, allowing it to be within the reach of the average consumer.

The contents of proposed H.R. 5470 is of utmost importance in the introduction of electric cars. It is designed to assist in the research and development of improved battery technology, and also to encourage the smaller independent manufacturers like ourselves. With a certain amount of financial assistance and actual vehicle procurement commitment, it would be a certainty that our program could move rapidly ahead. We, being a privately capitalized corporation, have already invested a considerable amount of capital in our development. If Congress does determine the availability of funds for this purpose, we would welcome ERDA funding to assist us in completing our development work to produce the multi-purpose commuter vehicles in sufficient quantities to satisfy government evaluation and actual consumer usage.

In conclusion of our testimony, we would like to point out the Motor Vehicle Manufacturers Association report of 1972 indicates the majority of trips taken in cars were less than five miles long. It is important that the government recognizes this dire need and is instrumental in implementing this quite evident use of electric commuter cars which could satisfy these needs, and also help alleviate our dependency on oil imports and assist in the elimination of air and noise pollution in our cities.

Again, Mr. Chairman, we wish to thank you for this opportunity to comment on this bill, and we will be happy to assist you in any way possible.

ELCAR PROTOTYPE ELECTRIC-POWERED MODEL 4000

Front axle.—Load rating: 1,350 lbs.

Rear axle.—Load rating: 1,650 lbs. Positive traction ratio 7.6 to 1.

Seats.—Vinyl, individual driver and passenger with adjustable seat track. Optional rear compartment jump seats.

Springs.—Front and rear coil springs.

Steering.—Rack and pinion, turn diameter: 24 ft.

Battery.—12–12 volt, 100 amp./hr.

Power system.—48v–240 amp./hr. Series parallel direct drive.

Motor.—6 h.p.

Range.—40 miles.

Top speed.—38–40 m.p.h.

Body.—Reinforced fiberglass. Closed body with two full side doors and rear hinged tailgate access door.

Shocks.—Hydraulic—front and rear.

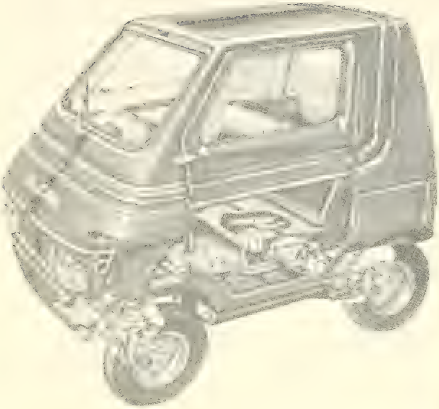
Tires.—SR 145 x 10.

Chassis frame.—Rectangular 10-gage construction.

Brakes.—Duo-Servo Split Hydraulic, self-adjusting.

Cargo space.—Rear: 50 cu. ft. Passenger side (less seat): 25 cu. ft.

Standard miscellaneous equipment.—Lights: Headlights, Parking, Tail and Stop, Directional Signals, 4-Way Hazard Flashers, Side Markers, Back-up Light, Horn, Windshield Washer, 2-Speed Electric Windshield Wipers, Sun Visors, Outside Rearview Mirror.



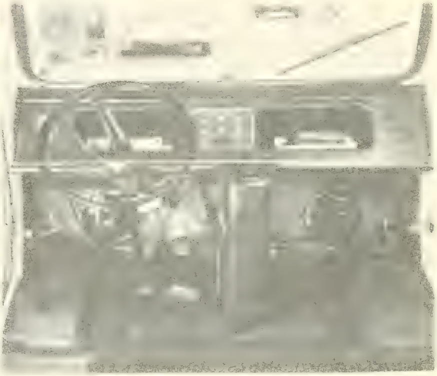
The Elcar body is constructed of unitized, high impact, reinforced fiberglass mounted on a chassis frame of 11 gauge rectangular steel. Full frame side doors are equipped with safety glass sliding windows and locks. Tires are 145/10 Michelin radials

The suspension is a independent coil spring type with hydraulic shock absorbers. High impact steel bumpers with polyurethane strips offer additional protection. The windshield is of laminated safety glass and the Elcar is equipped with all conventional driving and turn lights.

The eight batteries are nested below the floor in a convenient compartment that slides out for easy servicing.

By having the batteries below the frame a very low center of gravity is achieved which contributes greatly to the car's handling stability and driving safety.

Interiors are of heavy-gauge vinyl upholstery and the floor is covered with noise-absorbing mats. The driving controller provides three forward power speed selections and one reverse. Steering wheel, brakes and accelerator pedals are conventional. The car is equipped with drum type, hydraulic piston driven 4-wheel brakes There is also a manual park brake.



The Elcar carries a 12-month warranty on the motor, drive train and wear parts. Batteries and tires carry a pro-rated warranty.

While mechanical problems (because of the Elcar's simplicity of operation) will be at a minimum, repairs can be made quickly at the dealer where you purchased the car. A complete owner's operating manual is provided

SPECIFICATIONS AND STANDARD EQUIPMENT

Height 63.5"
Length: 84"
Width: 53"

Weight 1091 lbs
Wheel base 51"
Front track 43.3"

Rear track 42.5"
Ground Clearance: 5"
Tire size. 145/10

Transmission Rear axle drive mount
Motor. 48 volt energized excited
Non-corrosive fiberglass body
Vinyl upholstery with two padded sun visors
Three-point seat safety belts
Sliding door safety glass windows with locks
Windshield wiper and washer
Adjustable seat track
Storage compartment area
Two contour front seats
48 volt battery charger
Speedometer with mileage trip recorder
Low battery indicator
Side and rear view mirrors
Horn and all running lights

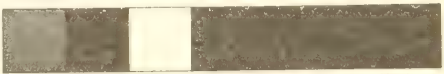
OPTIONAL EQUIPMENT

Radio
Heater
Courtesy lamp

Spare tire and jack
Wheel covers

Spare tire air and sealer
Single car trailer

The Elcar is now available in these seven colors



Pervinca Blue	Arrancio Red	Avorio Ivory	Yellow Gold	Blue Metallic	Tabacco Brown	Verde Green

ELCAR CORPORATION
Elkhart, Indiana 46514

Specifications subject to change without notice

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Mr. McCormack. I also want to reobserve that if there is any person or group who would like to submit information for the record we would very much appreciate having it. We are, of course, limited in the amount of time available for hearings, and I'm sure you are aware that the Members of Congress are under extreme pressure as far as our personal schedules are concerned, to attend a large number of meetings and to attend to thousands of details that keep us under very heavy pressure at all times. We will, however, welcome any written testimony that is submitted to us.

I am pleased at this time to welcome Professor Thornton of MIT.

I am sorry, Mr. Thornton. I do not have your title or background before me, so I would like it if you would introduce yourself, as far as your occupational background, and welcome to our hearing.

If you would like to submit your statement for the record, and then speak from it, you are perfectly free and welcome to do so.

STATEMENT OF DR. RICHARD D. THORNTON, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MASS.

Dr. Thornton. Thank you.

I have submitted written testimony. I will deviate slightly from that, to take advantage of comments that have been made previously in the hearing.

[The prepared statement of Dr. Thornton follows:]

Testimony of Dr. Richard D. Thornton, Before the Subcommittee on Energy Research, Development and Demonstration

INTRODUCTION

I am pleased to present testimony on what could be a landmark bill for advancing the development of electric vehicles and for reducing our dependence on petroleum for transportation. For almost 10 years I have been involved in research and development on various aspects of electric vehicles, and have tried on several occasions to persuade members of congress to take a more active role in advancing the cause of electric propulsion. As a strong believer in the potential for electric propulsion I can whole heartedly endorse the objectives of H.R. 5470.

I am sure that most of the members of this committee are familiar with the more obvious advantages and disadvantages of electric cars, and have ridden in one or more of the numerous electric cars now in use on our roads. Let me not waste time belaboring basic issues that are well known and are adequately discussed in existing literature. I recommend particularly the Oct. 17, 1974 issue of "Machine Design," and recent issues of "Electric Vehicle News" as good sources of basic knowledge. In my testimony I would like to concentrate on aspects of electric vehicle research, development, and demonstration that are not well documented, but are known to serious workers in the field and which must be recognized if this Act is to be successful. These "behind the scenes" issues concern underlying technological, economic, political, and institutional problems that have handicapped all efforts in this field for the last decade.

SOME FACTS AND OPINIONS CONCERNING ELECTRIC CARS

Let me start with a presentation of what I believe are 4 basic facts that can be proven rather conclusively, and two subjective opinions based on personal observations for the last 10 years.

Fact 1.—It is very hard to distinguish facts from opinions in any talk or paper concerning electric vehicles. One can find an article in a creditable journal that will support almost any hypothesis, and gross exaggerations and misrepresentations are very common. The errors arise from neglect of important issues, very unreasonable assumptions, or just plain fuzzy thinking. Thus, I caution members of this committee to be particularly skeptical in interpreting what they see and read, and to seek first rate advice from a variety of sources.

Fact 2.—The energy efficiency of an electric car is essentially the same as for a gasoline powered car. If an electric car is charged from a power grid supplied from an oil burning steam turbine, then the amount of oil burned by the generator is essentially the same as that required to produce the gasoline to power a conventional car. Both vehicles achieve between 10% and 15% net energy efficiency under typical urban driving conditions, and differing methods of measuring efficiency make it impossible to compare the two technologies too precisely. All attempts I know of that purport to prove that one technology is capable of substantially more efficiency than the other resort to unreasonable assumptions or comparisons. Obviously a small, light car is more efficient than a large heavy one, and also a car equipped with the most advanced energy saving features will be better than a more basic design. Both electric and gasoline technologies can eventually achieve higher efficiencies, but it would be premature to predict which technology has the greatest potential for energy efficiency. From an energy point of view the advantage of the electric vehicle is that it can be charged from generators that do not consume petroleum, can be charged in off-peak hours, and it can be charged from unconventional energy sources.

Fact 3.—Even with mass production economies, todays technology would not allow us to make an electric car as cheaply as we currently make gasoline cars, assuming comparable levels of performance. The best we could hope for is to make a substantial sacrifice in power and range and hold the cost to about the same level as for a similar size gasoline powered car. In actual fact the market for this reduced performance car will be substantially smaller so that the full advantage of mass production cannot be realized; thus the electric car will carry a higher price tag in the foreseeable future. There is reasonable hope, however, that reduced maintenance and operating costs could make the electric car attractive for certain applications. As a point of comparison, note that in the case of industrial lift trucks the gasoline powered vehicles have a lower initial cost but the electric versions have offsetting advantages that, for some applications, justify their use on a purely economic basis.

Fact 4.—The United States has a poor track record in the development of new technology for ground transportation. The automotive industry has achieved its success through its production and marketing knowhow, and is not noted for its technological innovation (although recently their R and D efforts have been expanded considerably). In the area of railroads we lag behind many countries in the exploitation of new technology, and the effectiveness of our research efforts on high speed ground transportation have been very discouraging. In the area of Personalized Rapid Transit we may someday play a leadership role, but results to date have been very disappointing. In all of these areas the basic problem has been an inability or unwillingness for a combined industry and government team to mount a sustained development program that coordinates the Research, Development, and Demonstration in a meaningful way over a long period of time.

We have done very well at mounting sustained, government financed development efforts in areas related to military or space programs, but non-military programs that demand a high level of technological evolution and a long time scale typically run into problems with our budgetary and political procedures. It is hard to think of a case where the US government has been successful in advancing the cause of new transportation technology except where there was a direct military related incentive. We see a never ending sequence of delays, cost overruns, premature committment to the construction of full scale hardware, and abandonment of programs in midstream. In short, we are prone to prematurely emphasize the Demonstration phase of a new program and down play the time and effort required for the important Research and Development phases. This is in marked contrast to a number of successful long term civilian R and D programs that have been carried out in Germany and Japan.

OPINION 1

Electric propulsion will play an increasingly important role in the evolution of future transportation systems and technology. It is possible that by the year 2000 a substantial fraction of the automobiles could embody some aspect of electric propulsion, but any effort to achieve this result in much less time is doomed to failure. Even this 25 year time scale demands concerted and imaginative action in the near future.

OPINION 2

The electric vehicle bill as now worded will do a disservice to the advancement of electric propulsion. The time scale is much to short, the early emphasis on large scale procurement is inappropriate, and the importance of sustained research and development is not recognized. Getting more electric cars on the road without advancing the technology will only produce expensive and discouraging results.

TECHNICAL AND ECONOMIC FEASIBILITY OF H.R. 5470

There is no way that the objectives of this bill could be achieved in a three year time scale. Any attempt to launch an extensive demonstration program on a three year time scale is guaranteed to lead to massive delays and cost overruns, and the end product will not be indicative of current knowhow. If you were willing to purchase an exact replica of an existing electric car, then it might be possible to receive delivery of several thousand vehicles within three years. But there is no way that any innovation could be incorporated into the vehicles, or that any follow-on evaluations could be completed.

The most important aspect of this Act should be research and development on better batteries. Even a factor of two increase in energy and power capability could have a profound effect on the suitability of electric vehicle for urban applications, but without any improvement there is substantial doubt that the demonstration program will be successful. Unfortunately the development of new or improved batteries is unbelievably time-consuming and even a five year time schedule causes difficulty. I have discussed the problems of battery research with directors of research for two large battery companies, and also with several individual inventors of new battery concepts. The universal feeling is that battery research is extraordinarily slow and frustrating, and development costs can be huge. Unless one is able to make major improvements in the methodology of battery research, there is a great deal of time consuming trial and error required. For example, one of the most important parameters of a battery is the life expectancy, and measurements of aging characteristics are inherently time consuming. Also, several batteries that have looked good in the laboratory have, to date, failed to be commercially viable because of production costs and manufacturing problems.

It is also important to do work on better motors and controls, and this also requires at least three years to demonstrate feasibility and five years to complete adequate testing, evaluation, and prototype production.

SUGGESTED CHANGES IN H.R. 5470

I cannot state too strongly my feeling that the time scale of this bill must be reconsidered, with major expenses for the Demonstration phase postponed two or three years. Let's not create another "Morgantown" by too early a commitment to unproven designs. Let's learn from numerous past mistakes and spend the necessary time on research and development prior to large hardware commitments. I feel this bill should be rewritten as a five year program with at least half of the money going into the Research and Development portion. A more modest, but more carefully planned demonstration phase should be conducted only during the last two or three years. The long range plan should envision a second five year program IF the first five year effort is encouraging, and during this second program the expenditures for Demonstration could be expected to be several hundred million dollars.

In lieu of the proposed initial "state of the art" procurement, I suggest we take advantage of the several hundred existing electric vehicles to perform careful measurement and evaluation, and generate a body of "hard" facts that can be used for future planning. I am sure that many of the existing vehicles could be leased or purchased for purpose of testing, and that they could even be evaluated in actual operation for certain application areas. This mini-demonstration phase could run in parallel with the initial R and D phases, and the results could be used for planning the main Demonstration phase.

For the main demonstration phase I would recommend against large scale procurement, but rather favor procurement of a smaller number of more carefully designed vehicles and a more thorough evaluation. Again, avoid premature commitment to full scale hardware.

In planning the demonstration program you must recognize that it may be hard to produce an advanced design vehicle from a single company. In this field the companies that have the financial and production capability to produce these vehicles often lack the incentive to produce vehicles because of the limited market they foresee. The numerous small companies who would like to produce vehicles for this type of demonstration may have technical capability but often lack both financial and production resources. A consortium of several companies could be particularly attractive, and I would urge this mode if possible. I note that Japan has for some years, had an active program involving a variety of companies working on different aspects of the problem. Incidently, we should make maximum use of results of the Japanese research.

Except for the too-short time scale, I believe the principle R and D issues are covered in the existing bill. Principally we need batteries which can store more energy per pound, which can deliver higher peak power per pound, but with costs per pound substantially higher than existing lead-acid batteries. We also need lighter weight and less expensive motors, and lower costs and higher reliability control systems. Issues of safety and drivability need further attention, and methods of reducing vehicle weight should be explored.

If this Act is passed, the first item of business might be to convene a one month study program by experts on various aspects of the problem: I am sure this group could come up with a set of well conceived, specific recommendations for the R and D program. It seems premature here to make recommendations concerning detailed research topics.

THE FUTURE OF ELECTRIC PROPULSION

So far I have limited my comments primarily to the development of on-the-road electric cars, but there are other aspects of electric propulsion that should be of interest to this committee. The entire area of high speed ground transportation depends on electric propulsion, whether for trains, air cushion vehicles, or magnetic levitation. I have been involved in the development of linear motors and magnetic levitation and see a substantial potential to reduce our petroleum consumption. Unfortunately research in this area has been almost completely thwarted by political and budgetary decisions. A carefully planned R, D and D program which recognizes the time required, and which concentrates on Development before Demonstration, is sorely needed. The energy payoff could be substantial, and ERDA is a reasonable agency to become involved in this development.

Another aspect of electric vehicle-development that has not been widely appreciated is the extent to which this interrelates with other energy programs. For example, wind and solar energy systems could be excellent energy sources for use in conjunction with electric vehicles. The vehicle's batteries can often be charged when the wind blows or the sun shines, and the expensive energy storage and power conversion facilities are already part of the vehicle and need not be replicated in the wind or solar system. I am currently in the process of building a solar heated house and find it frustrating to know that I will be wasting almost $1000 worth of energy a year because my collector will only be fully utilized about 4 months out of the year. It is clear that if we can mass produce power tools, outboard engines etc. for relatively low costs, we could also manufacture economical heat engines that could generate electricity from steam produced by otherwise idle solar collectors. An electric car with interchangeable batteries would be an ideal load for utilizing this readily available energy.

In assessing the type of vehicle for which electric propulsion is suitable, I believe the Committee should recognize the bus as a prime contender. Electrically propelled vehicles tend to get better as they get larger, and several studies have shown that even with todays technology, the electric bus could probably be made competitive with gasoline buses for many types of applications. Here the advantages are low air and noise pollution for vehicles which inherently operate in crowded areas. In addition they may have some advantage in energy efficiency because of the ability to recover energy during deceleration (the possibility is more significant for a bus than for a car), and the potential for reduced operating and maintenance costs may provide economic advantages.

SUMMARY

The Electric Vehicle Research, Development, and Demonstration Act of 1975 is an imaginative and timely piece of legislation. I heartily endorse the bill and would be pleased to do anything I can to help it on its way. However, I am disappointed that there is a preponderant emphasis on short term demonstrations since I do not believe that the major problem is one of increasing the public awareness. There has never been any major opposition by the public to electric cars, and if industry knew how to build vehicles that had the potential for mass acceptance, they would have done so. The hard fact is that the best vehicle we can build is either too poor a performer or too expensive or both, and no amount of wishful thinking can rectify this. Only a sustained Research and Development program has the potential to change these facts. A carefully planned Demonstration program can be helpful in quantifying the problem and in overcoming certain institutional barriers, but the demonstration of an inferior product will not produce a favorable response. I recommend that the program be stretched out to 5 years, that the first half of the program concentrate on research and development, and that the demonstration phase be more modest, but also more carefully planned.

DR. RICHARD D. THORNTON

Richard Thornton received his BS in Electrical Engineering from Princeton University in 1951 and his SM and ScD from MIT in 1954 and 1957. He became an Instructor in Electrical Engineering in 1951 and in 1957 joined the MIT faculty where he is currently Professor of Electrical Engineering. He has been involved in teaching and research on solid state electronic circuits and devices, electronically controlled electromagnetic devices, and computational methods for engineering design. He was a faculty adviser and promoter of the 1968 MIT-Caltech Electric Car Race and the 1970 Clean Air Car Race. His work on transportation related technology includes design, construction and testing of both battery and battery-gasoline hybrid types of electric cars, with particular emphasis on development of motors and controls. Recent research has been on linear synchronous motors and magnetic levitation for high speed ground transportation, and new types of electronically controlled linear and rotary machines.

Dr. Thornton was a principle member of the Semiconductor Electronics Education Committee and coauthored 3 books produced by the SEEC ["Characteristics and Limitations of Transistors", "Multistage Transistor Circuits", and "Handbook of Basic Transistor Circuits and Measurements"]. He was guest editor of the IEEE Proceedings special issue on Transportation in May 1973, and has authored numerous papers on electronic circuits, magnetic levitation, electric vehicles, and linear motors. He holds 7 patents (4 jointly with others) and received the IEEE Baker award for an outstanding transactions paper.

In 1964 Dr. Thornton was a principle founder of Thornton Associates Inc., a small electronics company involved in design and manufacturing for educational and industrial applications. In this company he has recently been involved in the development and manufacture of products for use in high school and college Physics teaching, instruments for control and monitoring of water purity, medical diagnostic equipment, and high power electronic controllers for use with batteries and motors for electric vehicle applications. Dr. Thornton has also consulted for several companies including Black and Decker, Electrolux, RCA, and United Carr Fastener.

Dr. THORNTON. I am pleased to present testimony to this committee on a very important piece of legislation.

For 10 years I have worked at MIT on research and development on new technology for electric propulsion for ground transportation, and am now more convinced than ever of the potential for electric propulsion to contribute toward our national goal of energy independence.

In order to give perspective to my testimony, let me summarize my experience very briefly.

In 1965, I initiated research on new ideas for motors and controls for electric cars. In 1968, I was the faculty sponsor for the MIT-

Caltech Electric Car Race, and in 1970 I worked with the MIT group to promote the Clean Air Car Race, and to construct and operate a gasoline-electric hybrid vehicle. More recently, I have worked on linear motors and magnetic levitation for high speed ground transportation.

In conjunction with the MIT work I have had a chance to have extensive visits and discussions on issues of electric propulsion with several industrial firms, including GE, Ford, General Motors, Garrett, TRW, and ESB. One advantage of an academic affiliation is greater access to engineering personnel in a variety of industries.

I also am a director of three small companies, and was a principal founder of Thornton Associates, which is currently involved in manufacturing electronic controllers for electric vehicles. In this context, I feel I understand some of the basic financial, marketing and technical problems faced by the numerous entrepreneurs who are trying to contribute to the advancement of electric vehicles.

In developing my testimony, I have tried to consider both the technological and nontechnological aspects of electric vehicles, and to make recommendations primarily on the basis of what I believe is in the best interest of the country.

Let me start with a presentation of what I believe are the four basic facts that can be proven rather conclusively.

FACT 1

In the field of electric vehicles it is very hard to distinguish a fact from an opinion. One can find an article in a creditable journal that will support almost any hypothesis, and exaggerations and misrepresentations are very common, and more so in this field than almost any other I know. The errors arise from neglect of important issues, very unreasonable assumptions, or just plain fuzzy thinking. Thus, I caution members of this committee to be particularly skeptical in interpreting what they see and read, including what I say, and to seek first rate advice from a variety of sources.

However, I can assure the committee that the testimony you have received here to date is excellent, and you should pay particular heed to the comments of Dr. Kane of ERDA. His comments show a thorough understanding of the issues.

FACT 2

The energy efficiency of an electric car is essentially the same as for a comparable gasoline powered car. All attempts I know of that purport to prove that one technology is capable of substantially more efficiency than the other resort to unreasonable assumptions or comparisons. Obviously, a small, light car is more efficient than a large heavy one, and a car equipped with the most advanced energy saving features will be better than a more basic design. Both electric and gasoline technologies can eventually achieve higher efficiencies, but it is premature to predict which technology has the greatest potential for energy efficiency. From an energy point of view, the important advantage of present day electric vehicles is that they can be charged from generators that do not consume petroleum, and can be charged at times that are most advantageous for the energy source.

FACT 3

Even with mass production economies, today's technology would not allow us to make an electric car as cheaply as we currently make gasoline cars, assuming comparable levels of performance. The best we could hope for is to make a substantial sacrifice in power and range and hold the cost to about the same level as for a similar size gasoline powered car. There is reasonable hope, however, that reduced maintenance and operating costs could make the electric car attractive for certain applications. As a point of comparison, note that in the case of industrial lift trucks the gasoline powered lift trucks have a lower initial cost, but the electric versions have offsetting advantages that, for some applications, justify their use on a purely economic basis. For most applications, however, the electric car is not cost-effective with today's technology, and noneconomic justification is required.

FACT 4

The United States has a poor track record in the development of new technology for ground transportation. The U.S. automotive industry has achieved its success through its production and marketing knowhow, and it has not been noted for its technological innovation, although recently their R. & D. efforts have been expanded considerably, and I think you will see a change in this situation. In the area of railroads we lag behind many countries in the exploitation of new technology, and the effectiveness of our research efforts on high speed ground transportation have been poor. In the area of personalized rapid transit we may someday play a leadership role, but results to date have been very disappointing. In all of these areas the basic problem has been an inability or unwillingness for a combined industry and Government team to manage a sustained development program that coordinates the research, development, and demonstration in any meaningful way over a long period of time.

We have done very well at mounting sustained, Government financed development efforts in areas related to military or space programs, but for nonmilitary programs that demand a high level of technological evolution, we've run into problems with our budgetary and political procedures. We see a never ending sequence of delays, cost overruns, premature commitments to the construction of full scale hardware, and abandonment of important programs in midstream. In short, I guess it's the national personality that we're prone to prematurely emphasizing the demonstration phase of a new program and downplay the time and effort required for the important research and development phases. This is in marked contrast to a number of successful efforts of civilian R. & D. programs that have been carried out in Germany and Japan.

To comment particularly on the Japanese program, I note that a substantial electric vehicle development has been going on for some years, now, but Japan has yet to get into a major demonstration phase.

Based on these four facts and other considerations, let me express the following opinions:

OPINION 1

Electric propulsion will play an increasingly important role in the evolution of future transportation systems and technology. It is possible that by the year 2000 a substantial fraction of the automobiles could embody some aspect of electric propulsion, but any effort to achieve this result in much less time seems doomed to failure. Even this 25-year time scale demands considerable concerted and imaginative action in the near future. The issue is not one of postponement or of playing down the importance of immediate action, but rather one of focusing on a long term objective.

The electric vehicle bill as now worded would do a disservice to the advancement of electric propulsion. The time scale is much too short, the early emphasis on large scale procurement is inappropriate, and the importance of sustained research and development is not recognized. Getting more electric cars on the road without advancing the technology will only produce expensive and discouraging results.

I believe there is no way the objectives of this bill could be achieved in a 3-year time scale. Any attempt to launch an extensive demonstration program in this timeframe is guaranteed to lead to delays and cost overruns.

The most important aspect of this act should be long term research and development on better batteries. Even a factor of two increases in energy and power capability could have a profound effect on the suitability of electric vehicles for urban applications. Unfortunately, the development of new or improved batteries is unbelievably time-consuming, and even a 5-year time schedule causes difficulty. Unless one is able to make major improvements in the methodology of battery research, there is a great deal of time-consuming trial and error required. For example, one of the most important parameters of a battery is the life expectancy, and measurements of aging characteristics are inherently time-consuming. Also, several batteries that have looked good in the laboratory have, to date, failed to be commercially viable because of production costs and manufacturing problems.

Although batteries are the main problem, I also feel that substantial effort should be expended on development of lower cost and higher performance motors and controls. To justify this, I point out that existing electric cars are substantially underpowered, and yet the cost and weight of the motor and control is a significant item. If the battery development program is successful, we would find the propulsion deficiencies would take on major proportions. Now is the time to anticipate this problem and initiate basic research and development. This effort should emphasize the reduction of costs and the achievement of reliable, efficient, low maintenance propulsion systems for on-the-road vehicles.

SUGGESTED CHANGES IN H.R. 5470

I cannot state too strongly my feeling that the time scale of this bill must be reconsidered, with major expenses for the demonstration phase postponed 2 or 3 years. Let's not create another "Morgantown" by too early a commitment. Let's learn from numerous past mistakes and spend the necessary time on research and development prior to large hardware commitments. I feel this bill should be rewritten as a 5-year program with at least half of the money going into the R. & D. portion. A more modest, but more carefully planned demonstration phase should be conducted only during the last 2 or 3 years. The long range plan should envision a second 5-year program if the first 5-year effort is encouraging.

In lieu of the proposed initial state-of-the-art procurement, I suggest we take advantage of the several hundred existing electric vehicles to perform careful measurement and evaluation, and generate a body of hard facts that can be used for future planning. I am sure that many of the existing electric vehicles could be leased or purchased for the purpose of testing, and that they could even be evaluated in actual operation for certain applications. This minidemonstration phase could run in parallel with the initial R. & D. phases, and the results could be used for planning the main demonstration phase.

The Post Office electric vehicle fleet is an excellent possibility for use in this preliminary demonstration phase. I know that the Post Office has spent over 3 years in planning and going forward with their procurement program.

As an estimate of the time scale involved in this kind of an effort, I specifically draw your attention to the results of the EPA study for Los Angeles. They show conclusively that the current state-of-the-art can contribute little to the solution of the pollution or energy problems, but the long term potential for electric vehicles is substantial. Let me quote a key sentence from page 100 of this report: "Among individual cases, those involving lead-acid battery use seem least desirable. 1980 impacts are trivial, and the cost of attaining them considerable."

One of the objectives of this bill is to assist small companies, and I believe a large demonstration phase would eliminate any possibility for a small company to compete. Note that the 350 vehicles purchased by the Post Office provided no benefit to small companies. In order to assist companies with more modest financial resources, I would encourage you to specifically designate some fraction of the money to be expended for innovative designs, not procured through competitive bidding. When building highways or buying fleets of IC-powered cars it is very appropriate to use a bidding technique, but for research and development and for innovative design of electric cars we vitally need new ideas that are not well handled by this mechanism. I think in many areas of the civilian R. & D. we have lost a lot of imaginative designs through a dominant emphasis on competitive bidding.

LIFE CYCLE COSTS OF ELECTRIC VEHICLES

A number of the questions posed by the members of this subcommittee have focused on life-cycle costs. This is a very important subject on which I would like to comment.

I have examined the EPA sponsored Los Angeles study, and find it to be a commendable piece of work. It is neither pro-nor anti-electric vehicles, but in fact is very objective. The eight conclusions on pages 12 to 14 should be required reading by the members of this committee.

If the costs of operating lead-acid battery cars appear to be high in this report, let me point out the further discouraging facts.

1. This report was initiated before electric car costs escalated. The report assumes an electric power cost of 1.9 cents per kilowatt hour instead of the rate of 4 to 5 cents, which most consumers now pay. This fact alone means that we should add 2 cents to the projected cost per mile. Projections for the cost of gasoline were 50 to 80 cents a gallon, which is much more commensurate with current prices.

2. When you examine the Post Office procurement, note that they have done a careful study and wisely opted for a long life, though more expensive, battery. Moreover, they will no doubt buy the best charging equipment, and instruct their drivers and maintenance people in the proper care and feeding of these cars. Even with all these favorable factors, I personally doubt that they will do better than achieve the minimum life-cycle costs projected by the Los Angeles study. I would certainly encourage members of this committee to try to get data from the Post Office as soon as possible.

The costs can increase by a factor of 3 if the consumer opts for a lower initial cost battery, if he buys a less expensive and more poorly regulated charger, and if he abuses the battery in operation.

The question yesterday occurred as to why this wide range of 3 to 1 in projected battery costs. If you continually use a battery under very heavy drain, if you run the battery to complete discharge, if you overcharge the battery regularly, if you buy a poor choice for an initial battery, there is at least a 3-to-1 range in projected cost. This is not a cost that tends to be fairly constant. I think the Los Angeles report has very accurate data on this factor.

My recommendation is to assume that battery costs are equal to the fuel costs, and that the fuel costs are 4¼ cents per kilowatt hour. If you use the Los Angeles report value of 0.79 kilowatt hours per mile—By the way, this seems to be less than what the Post Office is expecting to use—this works out to 7.1 cents per mile for battery, and fuel alone, which I admit is somewhat discouraging.

You may ask why the English claim that electric delivery vehicles cost only half as much to operate as IC powered versions. Here are two reasons to consider:

In a recent issue of The Electric Vehicle News, the British correspondent states: "Electric fuel costs are one-fifth of gasoline fuel costs." This calculation is based on off-peak electricity at 1.2 cents per kilowatt hour versus gasoline at $1.20 a gallon. If we change the numbers to reflect cost in this country, the comparative ratio changes by a factor of 8.1. Under these conditions the fuel for the electric car is 64 percent more expensive than for the gasoline. Moreover, even this unfavorable number does not account for the indirect subsidy of the electric vehicle since it is not paying road taxes. It may be very wise for us not to charge road taxes to electric vehicles, but in comparing life-cycle costs, I believe we should compare on an equal basis. The Los Angeles report, by the way, does consider the road taxes as a part of the operating cost, and that adds to the cost that you see in that report.

A second reason for the English claim is that small delivery trucks operating in London offer an ideal application. Reliability is of importance, and provides direct cost savings.

I would also like to add some comments on hybrid electric vehicles. I note that Mr. Ottinger has introduced a companion bill that, in essence, expands H.R. 5470 to include hybrids. This is a reasonable step, and I particularly encourage the development of a hybrid bus.

However, I will take exception to Dr. Edward David's comments yesterday when he said that the hybrid vehicle control is no more complex than for a straight electric. I have been personally involved in the development of two hybrid vehicle control systems, and find the control systems to be much more complex. I refer you, for more details, to two studies by TRW and Aerospace Corp. done in 1970 for the Environmental Protection Agency. It is clear from examining those reports that there is considerable complexity involved in the hybrid vehicle control system. Because of this complexity, it appears to be more attractive to use hybrid systems in larger vehicles, particularly the bus. There are many other advantages of a hybrid bus such as, for example, in city applications it could operate as a trolley bus, so that it's sort of a dual mode vehicle. It can operate both underground and on the highway feeder system to the city. It is interesting to note that a major limitation of building a hybrid vehicle is the unavailability of a reasonably priced battery with sufficient peak power capability.

I personally would prefer to emphasize long term battery development, but if people have realistic new ideas on how to build an economical hybrid electric vehicle, they should certainly be pursued.

So far I have limited my comments primarily to the development of on-the-road electric cars, but there are other aspects of electric propulsion that should be of interest to this committee.

The entire area of high-speed ground transportation depends on electric propulsion, whether it be for trains, air cushion vehicles, or magnetic levitation.

I have been involved in the development of linear motors and magnetic levitation, and see a very substantial potential to reduce our petroleum consumption. Unfortunately, research in this area has been almost completely thwarted by political and budgetary decisions. The program was almost completely terminated in January by decision of the Office of Management and Budget.

A carefully planned R., D. & D. program which recognizes the time required, and which concentrates on development before demonstration, is solely needed. The energy payoff could be substantial, and ERDA is a reasonable agency to become involved in this development.

Another aspect of electric vehicle development that has not been widely appreciated is the extent to which this interrelates with other energy programs. For example, wind and solar energy systems could be excellent energy sources for use in conjunction with electric vehicles. The vehicle's batteries can often be charged when the wind blows or the sun shines, unlike cooking or heating your house, which must be done on a regular schedule. The expensive energy storage and power conversion facilities are already part of the vehicle and need not be replicated in the wind or solar system.

I am currently in the process of building a solar-heated house in Concord, Mass. I recently did a calculation and found I'd be wasting $1,000 worth of energy a year because any collector will be fully utilized only about 4 months of the year. It is clear that if we can mass-produce power tools, outboard engines, et cetera, for relatively low costs, we could also manufacture economical heat engines that I can connect up to my solar source to generate electricity from heat produced by an otherwise idle solar collector. An electric car with interchangeable batteries is an ideal load for utilizing this readily available electric energy source.

In assessing the type of vehicle for which electric propulsion is suitable, I believe the committee should recognize the bus as a prime contender. Electrically propelled vehicles tend to get better as they get larger, and several studies have shown that even with today's technology the electric bus could probably be made competitive with gasoline buses. Here the advantages are low air and noise pollution for vehicles which by their very nature operate in crowded areas. In addition, they have other advantages in energy efficiency because of the ability to recover energy during deceleration, and this possibility is particularly significant on account of the way in which a bus operates.

In summary, the Electric Vehicle Research, Development and Demonstration Act of 1975 is a timely piece of legislation, and with suitable changes I can heartily endorse the bill, and would be pleased to do anything I can to help it on its way.

However, I am disappointed that there is a preponderant emphasis on short term demonstrations, since I do not believe that the major problem is one of increasing public awareness. There has never been any major opposition by the public to electric cars, and if industry knew how to build vehicles that had the potential for mass acceptance, I believe they would have done so. The hard fact is that the best vehicle we can build is either too poor a performer or too expensive, or both, and no amount of wishful thinking can rectify this. Only a sustained research and development program has the potential to change these facts. However, carefully planned demonstration programs can be helpful in quantifying the problem and in overcoming certain institutional barriers. For example, it would be very helpful if I could buy an electric car and not have to pay additional insurance and taxes on that vehicle. Also, lower costs for off-peak power would be an inducement. Note that we already have a subsidy of electric vehicles because of the lack of a road tax on electricity.

Note particularly that the demonstration of an inferior product will not produce a favorable response.

I recommend the program be stretched out to 5 years, that the first half of the program concentrate on research and development, and that the demonstration phase be more modest, but also more carefully planned.

Thank you.

Mr. McCormack. Thank you very much, Dr. Thornton. I am sure we all appreciate your very well considered and sincere testimony this morning.

I have one basic question with respect to your testimony, and that is at the top of page 3 you said:

Even with mass production economies, today's technology would not allow us to make an electric car as cheaply as we currently make gasoline cars, assuming comparable levels of performance.

Certainly nobody disagrees with that point, but the concept of this legislation is, among other things, to try to demonstrate to the public that the electric vehicles of the next 10 or 15 years should not be expected to have comparable levels of performance, that, indeed, we are clearly talking about a vehicle with much lower levels of performance. It really is something that is strictly a second car, something to run back and forth in and do errands. Since we know that a very large percentage of all the travel in this country really is with that kind of vehicle, for short trips—somebody gave us some figures of more than 70 percent being less than 6 miles—it would seem to me that even the electric cars that could be produced today would be satisfactory for that purpose.

Now, this does not say that there will not be bugs, and it does not say that they would necessarily be cheaper than a gasoline-powered vehicle, but it does say that we would be burning less gasoline, among other things, and we will be learning a lot in the field.

This is the philosophy of the bill. Without arguing with you on your basic premise, that we should take more time and do more R. & D. and stretch the bill out and know more what we are doing, for all of which I respect you, your testimony, I'm curious about your response to this particular approach. The bill assumes that what we are trying to do is demonstrate to the American public that they do not need to have high horsepower or high energy vehicles for running short errands, and at the same time to be giving field tests for vehicles that do not burn gasoline.

Is there any reason why we should not go ahead with that phase of the program in the near future, nearer than you suggest?

Dr. THORNTON. You can, of course, build small energy efficient cars with IC technology as well as electric technology. You have to decide whether the main thing is to reduce energy consumption or to reduce gasoline consumption.

If one simply provided an incentive for people to own a small extra car, I believe you could make substantial energy savings right away. But I think that, even here, the electric car might have trouble competing with the gasoline-powered car, assuming industry, as I'm sure they would, came up with a comparable size car.

Now, I would make one exception to my comments. I guess two exceptions, although one I included in my comments.

The bus, I believe, is clearly a viable thing with today's technology. At the other end of the spectrum, for the very small car, there are advantages in the electric car. The reason is that when you get to very small size gasoline engines with rigid emission control requirements, it gets to be expensive. The engine is fundamentally very close to you with the noise and the fumes being more noxious. So it may be more practical to build a very small electric car than it is a small gasoline car. The problem here is one of acceptance. If you make the car smaller, the range and performance goes down.

You saw on the demonstration Tuesday, several good approaches to the problem of very small car design. These should be used as guides in your thinking.

You should look at the price tags, and the top speed, and the range that those vehicles achieve.

I believe that electric vehicles using existing technology will, without any Federal subsidy be sold and used. The companies that are producing them are reporting rather remarkable acceptance by the public. I question whether we need to do more than provide institutional encouragement, and so this phase of the demonstration, I think, could be handled without the direct subsidy of the vehicle, but rather with making it easy to own an extra car, as I commented earlier. This means if I only drive one car at a time, why shouldn't I have one insurance policy which covers two cars? Why should I pay very high property taxes on a second car?

We do have a number of barriers to a person owning a second small car. These should certainly be addressed by the proposed program.

I guess I feel that there are enough people willing to pay the price to buy these small cars that we don't need to provide direct subsidy to the public. Moreover, that makes a free marketing situation, which I think is going to be in the best interest of developing the right kind of car.

I'm desperately afraid of a Government low bid procurement policy of developing cars which will then be distributed in some way to people. I would much rather have a free market system, with encouragement through the best indirect means you can think of.

Mr. McCormack. Mr. Goldwater.

Mr. Goldwater. Professor, what would you think would be the public's reaction if we take today's state-of-the-art and build several thousand vehicles? Do you think they will then be stimulated to rush in?

Dr. Thornton. If you believe what the people are going to tell you in later testimony today and tomorrow, that seems like it might happen without any encouragement from Congress. Of course, people have been saying that for some time. But I think now there are people who are willing to pay the money to have a guaranteed transportation system, independent of what goes on in the Middle East, and that this has changed the impact. I believe that there are a substantial number of people who would buy small electric cars, with some stimulation of the industry and reduction of the institutional barriers. But I do not believe this has to happen through direct subsidy of the vehicles.

Mr. Goldwater. Your knowledge of this whole thing, through working knowledge and long-time experience, is not only of electric propulsion, but also with the internal combustion industry. If a consumer within the next 2 or 3 years, taking the current state-of-the-art in both types of propulsion, would have the opportunity to buy either an electric or internal combustion car, what's he going to buy?

Dr. Thornton [interrupting.] Right now he has no option. If he wants to buy a very small car, of the size of the ones you saw demonstrated, he has to buy an electric car or a foreign car. If you are asking whether U.S. automotive companies could come up with a comparable gasoline-powered car, I would rather they answer that question for you.

I think there are some people, for novelty reasons, for status reasons, for energy independence reasons, for a number of reasons, will elect to buy small electric cars.

I think you mislead yourself if you look too much at these mileage statistics, because it's not a question of whether a person 95 percent of the time can use an electric car. It's the fact that he has to have 100 percent transportation, and that if he can afford the extra car, as an absolute add-on extra car, then he would almost certainly use it where he could use it.

Mr. GOLDWATER. You seem to infer that people would not buy an electric car unless it was competitive.

Dr. THORNTON. No, I didn't say that. I didn't mean that, at least. There is substantial evidence by some of the current manufacturers that people would pay a substantial premium for an electric car that is as good, from a performance point of view, as a comparable gasoline-powered car. So there is a certain degree of consumer acceptance today.

Mr. GOLDWATER. Then you would agree that if we were to provide these moneys to create a demonstration, by this demonstration we may stimulate interest by the public and those who would be willing and therefore, that type of a provision may be good?

Dr. THORNTON. Subsidies will almost always produce a stimulation. The question is: How much stimulation do you want, and whether the net results of that stimulation are good or bad? My concern is that you have a fixed number of dollars. If you put too much of the money into the initial stimulation, 3 years from now you might have some people, who face the realities of the higher costs of operating those electric cars, who are discouraged, and you haven't done your homework to make the next generation of electrics feasible.

So a more modest stimulation program to sort of get some learning experience, so that when you really learn, when the country learns, what the issues are, they're in a position to go.

For example, take the nickel-zinc battery that Dr. David talked about. Just the change from lead-acid to nickel-zinc, and maybe it's only a factor of two improvements in energy density, produces a fantastic change in terms of the performance that could be realized by an electric car.

If, in fact, we're only 2 or 3 years away, it seems unwise to make a major stimulation of lead-acid battery-powered cars, when perhaps 3 or 4 years from now we can have very much better cars on the road.

Mr. GOLDWATER. You're, in essence, saying we can better use those limited available dollars by putting the work in the first phase, in research and development?

Dr. THORNTON. I also feel if you do that the program will seem more viable to the Office of Management and Budget, who's opinion must be considered here, unfortunately.

Battery research has paid off in many other areas, such as solar energy, and in peaking power, that it's a more general purpose type of development, and the Los Angeles study will be used to show you that you're not solving a major energy problem with promoting today's technology. Whereas, you can show that promoting tomorrow's technology does have some important energy consequences.

Mr. GOLDWATER. We have somewhat of a problem here, in that I think this particular bill's emphasis is primarily on demonstration.

We have attacked the research and development side of it in the ERDA bill. It is pointed out that we have close to $30 million just in battery research, fuel cells, and what-have-you. There is additional money in other types of energy or electrically related R. & D. that would be applicable to the electric car, and this particular bill puts emphasis on the demonstration of that.

I am just wondering what else perhaps we should be doing, other than that approach. We do have the money for the research and development. Now we're talking about demonstrating, and I would assume that your conclusion was we're demonstrating something we don't have, or demonstrating before we have what we're looking for.

Dr. **Thornton.** If you can think of this as a 10-year program, it would, in fact, be primarily a demonstration program. Politically, it seems hard to even talk about a 10-year program, and you sort of have to talk about a shorter range first step toward a 10-year program.

If it has to be a 3-year program, then I would like to think of this as the first of three steps; if it has to be 5 years, then it's the first of two steps; and that in any 10-year demonstration program, a major expense and effort will be demonstration. But it doesn't mean that the careful development and planning of the early stages must not be done first, and I believe in the concept that if we have a fixed number of dollars to spend in this area, we would like to allocate them in an optimum way.

Mr. **Goldwater.** Thank you, Mr. Chairman.

Mr. **McCormack.** Mr. Brown.

Mr. **Brown.** Dr. Thornton, you did a remarkably good job in answering most of the questions that I was going to ask in connection with your presentation.

I was interested in exploring some of the data on life-cycle battery costing that came up, and you explained to me why that wide range of per mile cost in the southern California study, I think, adequately.

I would ask, in connection with a statement that was made yesterday about the British experience, where they're citing a per mile cost for the electric vehicle as being a fraction—I think a half—of the ICE, you explained the reasons for that also, but I see the very distinct possibility that our electric costs and gasoline costs may over a 5-year period, say, approximate those in Britain, particularly as far as the electric cost is concerned, which is a rather arbitrary figure based upon costing the off-peak power.

Would you tend to agree with that, or disagree?

Dr. **Thornton.** There's no question that the cost of energy is going to go up, and probably very soon. It would be very easy to figure these things if you could project how the cost of oil was going to affect the cost of electricity.

In New England we generate a lot of electric power from oil, and the cost of electricity is going to probably go up as fast as the cost of oil. In fact, the problem gets worse in some sense because it used to be the cost of fuel was not the dominant item in the case of generating electricity. It's getting to be a dominant item. Since the energy efficiency is roughly comparable, you're burning about the same number of gallons of oil at the generator as you are burning gallons of gasoline in your car. But in the electric case you have to pay for the transmission and distribution.

So I can't see, in New England, for example, that the cost of electric vehicles will become more favorable. Now, in areas of the country that depend upon nuclear and other energy sources, it could very well be that the electric vehicle would become more attractive with time, and that's something to consider.

I don't know what the situation is in Los Angeles, but of course, there they have a major air pollution problem, and if, in fact, it appears that current emission control technology is not going to solve the problem, then you have added incentive for developing electric vehicles.

Mr. Brown. I was going to raise that question with you.

The figures given in the Los Angeles study indicate that one of the primary reasons for the attractiveness of the electric vehicle would be the potential for reducing petroleum use by a substantial fraction. In fact, they state that petroleum usage could be reduced up to one-third given 40 percent use of electric vehicles, that there would be a 33-percent reduction in oil with the use of electric vehicles.

In the light of these results and the event electric vehicles do become widely used by 1990, itself would be a major factor, with regard to overall supplies of petroleum almost without regard to cost. I presume if petroleum was in short supply, the cost for gasoline would be also substantially increased.

So that this is not exactly a question, but it casts some doubt on the validity of comparisons which are strictly economic. If the oil is not there and we are generating electricity with nuclear or coal, then electric vehicles become much more attractive. You would not disagree with that?

Dr. Thornton. That's a true statement.

Mr. Brown. Also, I did not notice in your statement too much reflection, but some, on the possibility of enhancing the desirability of electric vehicles by the kind of systems design, and I am here referring both to technical systems and social systems. Your use of, say, a windmill in New England to generate electricity and store that in a car battery, would be a technical system which would make the electric vehicle more desirable because you are using essentially free energy from wind. But a social system would be to prohibit the ICE vehicles from, say, a downtown area because of the emissions problem, and under those circumstances there would be almost no alternative, and considerable encouragement, to market a good electric vehicle.

Part of the purpose of this bill is to lead off the exploration of what I think you call barriers to the distribution and use of electric vehicles. We can either remove barriers, or we can set up incentives by prohibiting the ICE.

I am just wondering if that line of thinking would influence your, otherwise rather pessimitic, view about the legislation before us.

Dr. Thornton. If you take away what appears to be an emphasis on consumer electric cars, I'm much less pessimistic. For example, the kind of thing that has been proposed, I can't tell you how many times, would be to close off the central part of Los Angeles; you buy a fleet of 300 or 400 small electric cars, with some kind of a key rental system—systems like this are currently in use in Europe, by the way; we're way behind in this—whereby people can drive themselves back and forth in the inner city area by an automatic rental process using electric vehicles. This is an experiment which involves a government entity in sort of a commercial application of electric vehicles. I would encourage that.

The thing that I can't encourage is a subsidy of vehicles in the hands of consumers at large just to sort of replace existing vehicles. I would rather handle that by putting an energy assessment, through a gasoline tax, or whatever, and handle it that way and see what happens, and let the ICE people make their contribution, too.

But I do agree that there are things, as you suggest, that should be considered. In fact, one of the authors of the Los Angeles study many years ago was a prime mover in systems of this type. It should definitely be investigated.

Mr. BROWN. Just one further question.

The trend of your statement is to stretch out the demonstration, focus on the R. & D., and in that area primarily the battery R. & D., which runs completely opposite to Dr. David's testimony, who says, as you indicated, that they may have in 2 years a substantially more efficient battery, and they do not need Government-funded R. & D.

So if the major battery producers, of which Gould is a representative, take that position, where do we fiit into the R. & D.?

Dr. THORNTON. He only took that position relative to the nickel-zinc battery because that was so near fruition, and then I think his comments may be appropriate. He did not make any such statement relative to longer term R. & D.

Moreover, there is an obvious disinterest of the large battery manufacturer in seeing the Government support large battery research because there is no guarantee that that particular company would benefit in the long run from a long-term battery research program. You may remember that the automotive companies once discouraged Government support of research on emission controls.

I also suggested the motor and controls aspect, and I would claim that we don't yet have adequate motors and controls for the vehicle that would use the nickel-zinc battery system, and many people have alluded to the cost of the controls, and this is a very basic problem.

Mr. BROWN. Thank you.

Mr. McCORMACK. Thank you, Mr. Brown. Mr. Thornton.

Mr. THORNTON. Thank you, Mr. Chairman.

Mr. McCORMACK. I myself am very impressed by the written testimony of Dr. Thornton, and I have enjoyed the exchanges of questions and answers that we have heard.

I agree with the statement that in the area of large vehicle propulsion, the potential is greatest. It was not too many years ago that electric buses and trolleys were on the streets in many of our cities, and you do not even have to worry about the battery technology if you can have the overhead wires to provide power to vehicles on a continuous traffic pattern.

I wonder if it might be appropriate to spend some time in research in transmission technology, perhaps using electric generation and power drive applications, to develop an infinitely variable transmission system which could allow, as I suppose it does in the hybrid vehicle, the internal combustion engine to operate at its highest efficiency.

The reason I suggest this is that a few years ago I did have the responsibility of designing and building a fleet of one-quarter ton trucks for an enterprise which needed them to work in intracity traffic. I considered the electric vehicle, and rather than that, came up with a 30-horsepower internal combustion engine, an automatic clutch, infinitely variable drive, built the body out of fiberglass, the frame out of a single box member girder, et cetera. But the transmission characteristics of this vehicle really gave it great flexibility.

Is there a possibility of developing increased efficiency by means of transmission research, either in electric or some other means, Doctor?

Dr. THORNTON. There is no question that there are a number of possibilities. I think we all know now that the typical gasoline-powered engine in a passenger car operates at 30 to 40 horsepower and is capable of 200 horsepower, thus it is running at only about half of its maximum efficiency. Ideas such as disconnecting pistons when you're driving on the highway have been proposed, and anything you can do to make the gasoline engine smaller has the potential for higher efficiency.

The problem is with existing lead-acid batteries. For example, in the hybrid vehicle you're not limited now by energy, you're limited by power. As you go from an electric into a hybrid electric you have to put in the weight of the engine, so you have to take out some batteries. The power problem, which is already bad enough in the electric car, gets to be impossible.

If we had inexpensive but very high-peak power batteries, it would make a world of difference in the hybrid vehicle, and I would strongly encourage looks at ways of storing energy, relatively small amounts of energy, but in a way that you can take it out very fast.

Some research is even done on flywheel systems. There's still encouragement in this. I can't speak of the current state of the art, but it's certainly possible that a flywheel-based transmission for providing peak power has a great deal of potential.

So I think I'd answer your question, yes, if by normal transportation systems you mean systems that have some energy storage associated with them, and have better energy matching characteristics associated with them. But the power carried with them and the power available from an IC engine, yes, it's very worthwhile, and should be incorporated.

Mr. THORNTON. Among the battery sources, sodium-lithium batteries have some problems associated with them.

Are these the type studies that you think attention should be given to?

Dr. THORNTON. It might be that some of the high-temperature batteries could even be used in a hybrid system, where you use them only because they have some high, peak power capabilities.

I think we should expand the horizons on what we're looking for; don't just look for high energy; but look for high power; look for low costs; look for a variety of parameters that could influence electric propulsion.

Mr. THORNTON. I may be going a bit too far out with this, but I have been very interested in the possibility of the use of superconducting materials as storage for off-peak electrical requirements. I know that that would have tremendous problems in getting the size and transportability down for automobile applications. But certainly some way of storing and recovering power could really mean a significant breakthrough in this field.

Dr. THORNTON. Cryogenics are something I know about through my work on magnetic levitation, in which a vehicle uses superconducting coils. But, with today's technology, the energy storage is very poor from the point of view of transportation, and it would take an extraordinary breakthrough to make that viable.

But I think the sort of a program that starts off with no holds barred, and then narrows down to one or two concepts, with the hope of coming up with a peak power supply and transmission system, is a worthwhile program, both for electric vehicles and for IC vehicles.

Mr. THORNTON. Thank you very much, Dr. Thornton. Thank you, Mr. Chairman.

Mr. McCORMACK. Thank you, Mr. Thornton.

Mr. Hechler.

Mr. HECHLER. Just briefly, I have a little sensitivity, being a West Virginian, toward identifying Morgantown as a code word for too early a commitment to unproven designs. Yet I agree with your conclusion that that certainly is true.

I just would like to make the observation that there is a built-in delay factor in all of the manner in which Government operates, and industry operates, which I think will take care of the kind of things that you are concerned about.

What we really need are people who can push this whole project forward, instead of saying "Let's go slow."

Dr. THORNTON. You definitely want to push it forward. It's not a matter of stalling. It's a matter of planning and doing research and development first. And there should be no change in the sense of urgency of the legislation.

Mr. HECHLER. All I would observe is that there are lots of people in the Government bureaucracy who would just love to sit and plan, and plan, and plan, and never do anything.

[Applause.]

Mr. HECHLER. Thank you, Mr. Chairman.

Mr. McCORMACK. Thank you, Mr. Hechler.

Thank you, Professor Thornton. We very much appreciate having you here, and we appreciate your testimony, and you will prepare it so you can get a copy to the recorder. Thank you very much, sir.

Dr. THORNTON. Yes, Mr. Chairman. Thank you very much.

[Answers to additional questions submitted to Dr. Thornton follow:]

Electric Vehicles

Answers by Dr. Richard D. Thornton to Questions posed by the Subcommittee on Energy Research, Development and Demonstration

1. I believe the primary need is federal support of the basic Research and Development, and for removing certain institutional constraints. I do not believe that major direct subsidy of electric vehicles or large scale government procurement is necessary or desirable. There are currently a number of special purpose applications for which electric vehicles could be used, but these markets are already attracting commercial interests. There is a desperate need for incentives that will encourage the individual to reduce energy consumption for transportation, and such incentives should also help the electric vehicle industry. The federal government could also play a role in helping large cities to undertake electric vehicle experiments. These might involve major use of electric vehicles in certain downtown areas where air pollution is a problem, and electric power generation is not primarily from oil burning generators. I believe that existing procurement plans for the Post Office and by the electric utilities should be encouraged and expanded where possible.

2a. Low capital companies will fare very badly in any straight competitive bidding. Small companies in the electric vehicle field have great difficulty in attracting the capital required for any quantity manufacturing, and they usually lack the expertise to make an "effective" proposal.

b. Loan guarantees would help, but I would prefer to see small-lot procurement from a number of companies in which the price of each vehicle is high enough to allow creative evolution.

c. On any government supported R and D the government should give substantial patent rights to the companies. The idea is to encourage exploration of patents, not to look them up. Rigid patent provisions might prevent large companies from participating. Small companies can be encouraged by realistic payment schedules, and by more relaxed delivery schedules.

d. Some vehicles should be purchased from those available, not from a specification. A committee could evaluate all available vehicles, and specify several vehicles for single quantity procurement. These vehicles should then be thoroughly tested and then a quantity of one of two types should be purchased. Don't make the mistake of trying to buy all of the electric vehicles on the basis of a contract specification.

e. No

f. Safety standards should be based on the need for safety; for very small cars with limited speed you may need different standards, but don't compromise esential safety standards.

3. Electrification of transportation appears highly desirable where technically feasible.

a. For rural areas where air pollution is not now a major problem, centralization could have undesirable effects. For urban areas where the electric car is most suitable, the implied centralization is probably desirable.

b. The only reasonable alternatives are synthetic "chemical" fuels or a form of energy not yet considered practical for electric vehicles. It is hard to predict an invention, but it is the invention which will change the future.

4. The prospects for a suitable motor-control combination are very good, but existing systems are too heavy, poor on performance, or too expensive for a consumer product. Both electronic and mechanical components can be used. The combination of a microprocessor, high power electronic components, and some mechanical switching will probably be desirable. It is important to treat the motor and control together and not study controls as an isolated component. Methods of increasing reliability and decreasing cost are particularly important.

5. Maintenance should not be a major problem. Most maintenance should be associated with mechanical components similar to those in existing cars. Most of the electrical maintenance can be handled by existing shops provided the vehicles are adequately documented, and provided replacement parts are readily available. Since electric vehicles will not be used for long trips (in the near future, at least) the major question is whether the dealers can also handle the maintenance on the vehicles they sell.

6. Total energy use would be reduced except that new gasoline powered vehicles will probably be substantially more efficient. Perhaps the very small electric car will be more acceptable than the very small gasoline car, but if vehicle size does not change then energy consumption will not change much.

   a. For electric vehicles the extra weight of the batteries, and the relative inefficiency of the batteries are the major problems. If the battery weight can be reduced by a substantial factor, the electric vehicle would look much more desirable from an energy viewpoint.

   b. There is ample electric capacity for off peak charging, and it is unlikely that the number of electric vehicles will expand faster than can be accomodated by constructing new facilities. We don't know enough to make meaningful long term predictions, but of course, in the unlikely event of a major and sudden shift to electric vehicles, there would be all kinds of problems, including shortage of generating facilities.

7a.
b. Synthetic fuels would enhance the advantages of gasoline powered vehicles.

c. Flywheels could be used to advantage with all types of vehicles. I believe the main potential use of flywheels is for very short bursts of power for acceleration, not for major energy storage. Fuel cells have always seemed to be promising, but there seems to be a missing idea or two. ICE-electric hybrid vehicles seem to be attractive only for relatively large vehicles.

8. Heating and air conditioning are not important at this stage of electric vehicle evolution. Most electric vehicles resort to a gasoline heater, but with better batteries an electric heater is feasible. Air conditioning isn't necessary, yet, but with better batteries an electric air-conditioner can be used.

9a. Small cars appear to be less safe than large cars. Obviously, an electric vehicle avoids much of the problem of fire, but the heavy battery weight creates other problems.

b. There seem to be few hard facts on safety, and I would recommend destructive testing of a number of types of existing vehicles in order to assess the types of problems that arise. This testing should follow thorough technical and performance evaluation.

10. The battery requirements for electric vehicles are very different than for load-leveling large-scale energy storage. For vehicles weight is a serious problem; the ratios of power to weight and energy to weight must both be high for electric vehicles. I feel

we need major research that is specifically oriented towards electric vehicle batteries. This work should be coordinated with other relevant research, but should be independently funded.

11. For intercity travel we need a major improvement in ground transportation. The first step is to improve the railroads to performance levels that are common in other major industrialized countries. For the long range future I feel very strongly that a new technology, such as magnetic levitation, offers substantial promise to minimize petroleum consumption by automobiles and airplanes. If very small automobiles were in common use, we could even arrange to carry these on-board a high speed vehicle with improved energy efficiency and higher speeds.

   a. Electrified roadways seem to be too expensive to justify their cost, except for captive vehicles in an urban area. For personal vehicles I would recommend an "Instant rental"system with vehicles plugged into curbside charging facilities when not in use.

   b. Electric mass transit is a field in itself, and should not be a part of this program except for special demonstrations, such as the "instant rental" system described in (a).

   c. The fuel cell should be supported as an item of basic research if anyone can propose ways to overcome limitations of existing units. It is technically feasible, and fuel cell cars have been operated, but the problems are considerable.

12. We should definitely reduce energy going into transportation by all available means. We should not decrease the number of vehicles, but rather should provide inducements to people to own more vehicles, provided the added vehicles are small and efficient. We should encourage use of bicycles, and especially allow bicycles to be carried on public transportation systems. No one action can have a major impact, but the sum total of several actions can be significant.

13. The foreign dominance of all forms of new technology for transportation is a definite long term threat to US production. We must take an agressive action to increase all types of transportation RD and D, not on a crash basis, but over the long pull. Most international "cooperative" programs tend to have a "master-slave" relation.

14. Every demonstration has its own objective, and few generalities are appropriate. Usually a demonstration program is based on the idea that an existing technology is desirable, but is not used because of institutional inertia.

  a. In my opinion the state of existing technology does not justify a major electric vehicle demonstration program.

  b. A 3 to 5 year, low-key demonstration may be appropriate as a "fact-finding" exercise, although one or two years is possible by using existing vehicles. A major demonstration should be avoided until the R and D phases are complete.

  c. Advanced batteries would allow consumer evaluation under more favorable conditions, and with a much higher potential impact. A premature program will only "advertise" the shortcomings and make for greater skepticism when a better battery is available. Information learned for a lead-acid battery may not have much relevance for other batteries. I know of no disadvantage of the delay.

  d. We live in a world of limited resources. A parallel demonstration program will sharply curtail the kind of effort required for a successful R and D program.

  e. I don't believe that any benefits could be obtained with today's batteries.

  f. I believe cost increases of petroleum will primarily encourage smaller cars, and the electric could also benefit. Such increases might actually reduce the need for external stimulation of the electric vehicle field.

15. An effort on hybrid vehicles should concentrate on the bus or light rail, and not on the passenger car. However, new and well thought out ideas for a hybrid might justify basic research support.

16. A leasing aspect is highly desirable, as I mentioned in my original testimony. This type of demonstration can help overcome institutional inertia in a field where otherwise the electric car looks practical.

17. The safety problem of small cars operating in and around larger cars and trucks is a very real problem. Statistics and experiments both show the potential safety advantage of heavier cars. I believe that many people shy away from small cars because of the perceived safety problem. However, a large E-V can intermix with a large ICE without any unique safety problems.

18. A typical car, in urban use, expends close to half of the energy for accelleration. Moreover, the efficiency under constant speed conditions is only about 50% of what it might be if the engine were designed to operate only in this constant speed condition. I don't have detailed information on idling time etc., but fuel wastage is considerable. Strong incentives for energy efficiency should be created for both consumers and automobile manufacturers. Also, basic research on methods of improving efficiency should be supported in a major way.

19. The Aerospace report is:

    Final Report
    Hybrid Heat Engine/Electric Systems Study

June 1971
Report No. TOR-0059(6769-01)
Prepared for Advanced Automotive Power Systems Development
US Environmental Protection Agency

The TRW report was to the same agency at about the same time, but I don't have the details at hand. Dr. T. C. Wang, now at General Motors Research Laboratory, was an Author of this report and is an expert on controls; he might be able to give you more details. Dr. John Brogan who is now with ERDA, was involved in this program and could also give you more details. TRW probably did more work on controls than did Aerospace Corp.

The complexity of the control arises because the gasoline engine and the motor must both be controlled if efficient, low emission operation is required. I once thought the control could be fairly simple, but after designing two different controls, I'm convinced it isn't simple. Even the control of the motor alone turns out to be surprisingly difficult. Note that in a hybrid the electric motor and battery are smaller, and this tends to require more effort to optimize the control in order to get adequate performance.

Mr. McCormack. We have indulged ourselves in the luxury of really delivering a discourse to Professor Thornton here, and I am afraid we have gotten ourselves into a box on the schedule. We are going to have to adjourn for a full committee meeting in about 35 or 40 minutes, so we will go ahead with the next witness. But I think we are going to have to plan some alternate programs for some of the later witnesses in this morning's hearing.

Let us call Dr. Edward Campbell, executive secretary of the Electric Vehicle Council, as our next witness. I understand that you are accompanied by colleagues, Mr. Campbell. Please feel free to bring them to the table with you if you like, and introduce them as you wish.

How long will your testimony be, Mr. Campbell?

Mr. Campbell. Mr. Chairman, my remarks can be included in the record by paper, and I will just add a few summary remarks to it. I'll try to keep it short.

Mr. McCormack. I wonder, Dr. Currie, if I could ask you to meet someplace in the side of the room with the representatives, or the other persons who are going to testify this morning, and see if we can work out some kind of a schedule.

Mr. Campbell, welcome. If you wish to insert your formal statement in the record, it will be done without objection, and you may proceed as you wish.

STATEMENT OF EDWARD A. CAMPBELL, EXECUTIVE SECRETARY, ELECTRIC VEHICLE COUNCIL; ACCOMPANIED BY JAMES F. NORBERG, ADMINISTRATOR, ELECTRIC TRANSPORTATION PROJECTS, ESB, INC., CONNEL A. BAKER, TECHNICAL SERVICE ENGINEER, LEAD INDUSTRY ASSOCIATION, INC., AND ROBERT BRY, VICE PRESIDENT, DIVERSIFIED OPERATIONS, OTIS ELEVATOR, CLEVELAND, OHIO

[The prepared statement of Mr. Campbell is as follows:]

Prepared Statement of Edward A. Campbell, Executive Secretary, Electric Vehicle Council

By way of introduction, I'll explain what and who is the Electric Vehicle Council. The Council was formed in 1968 by the Edison Electric Institute, the principal association of America's investor-owned electric utility companies. The objective of the Council is "to advance the use of electricity in transportation." Today the Council is an international organization, with members from companies in 19 countries, in the electric utility, transportation, electrical equipment and battery industries. In addition, EVC membership includes other associations, and a large number of individuals, including representatives of universities, research laboratories, government agencies and others. In the United States, electric power companies are members of EVC by virtue of their membership in Edison Electric Institute.

The Council is administered by a staff, which I head, maintaining headquarters in New York City. It is governed by a nine-man Executive Board chaired by Mr. F. J. Port, President of ESB, Incorporated. The other eight members of the Board include four utility company presidents, three officers of manufacturing companies, and the director of a trade association.

Among its activities, the Council sponsored a program to develop, produce and put into use 107 battery-powered delivery vans, which were delivered to users during calendar 1974. The Council sponsors a biennial International Electric Vehicle Symposium, the most recent of which was held in Washington, D.C. in February, 1974.

This, then, is the Electric Vehicle Council.

Concerning the Bill which is the subject of these hearings, I would like to say at the outset that the Council heartily endorses the Bill, and particularly its primary goal, to demonstrate the commercial feasibility of electric vehicles, including the introduction of as many as 10,000 E.V.'s within three years. We also endorse the use of funds to promote research on the components used in electric vehicles. We compliment the Committee on their foresight in suggesting Federal action now, in anticipation of our eventual depletion of petroleum reserves and the gradual shift to primary dependence on electric power generated by coal and nuclear. Even today, only 16% of electric generation is from petroleum, on a national basis.

We concur that a federal role is needed to demonstrate battery-powered road vehicles on a substantial scale, to generate public awareness of their feasibility and social desirability, to support the development of an adequate maintenance and service network such as we now enjoy with gasoline-powered vehicles, to help remove legal or legislative impediments which may now stand in their way, and even to subsidize their sale. In this latter connection, section 8 of the proposed Bill deals with support of the use by government agencies of vehicles which "are practical but are not economically competitive with conventional vehicles." It is suggested that such support is needed for public and commercial use as well. When vehicles are produced only in thousands, their selling prices are bound to be 50 to 100% higher than comparable internal combustion engine vehicles which are produced in the millions.

The bill calls for the production in one year of 5,000 battery-powered vehicles built on conventional American automobile chassis—which we would refer to as "conversions"—and within three years, 5,000 vehicles specifically designed for electric power—which we refer to as being designed "from the ground up" for electric. These goals are quite feasible. Consider for a moment what we know about the present state of development. This past Tuesday, my organization assembled 18 electric vehicles on the Hill. Of these, 8 were commercial, namely 7 vans and one bus; while 10 were passenger vehicles. Of the 18, 8 were conversions and 10 were designed from the ground up. While 4 of these were prototypes, produced by component manufacturers for demonstration purposes, the other 14 have definite commercial feasibility right now. In fact, some are in commercial use; 350 of the AM General "Electrucks" are or will be in use this year by the US Postal Service; the Otis Electrobus is in regular revenue service in Long Beach, California, and elsewhere; and 1,000 of the little Sebring-Vanguards have been produced . . . just to name a few examples. In other words, I think the electric vehicle industry is demonstrating its capability.

Before proceeding, however, I should like to insert a comment on those words which we are all using these days, namely "electric vehicle industry." From the long view . . . let's say twenty years or so . . . I don't think we're looking for a new industry to challenge our present automotive industry. What I think we are looking for is an alternative power source in our automobiles and commercial vehicles . . . a non-gasoline source, if you will.

In that connection, I call attention for a moment to Section 4 of the proposed Act, which in the first paragraph states that such "vehicles will be primarily powered by portable sources of electric current but *may include also* a non-electrical source of power designed to charge batteries or provide auxiliary power to the wheel." This is what we would call a "hybrid." In view of the strong emphasis placed in the Act on the substitution of electric power for gasoline, it infers that gasoline-power should not be the secondary partner in a hybrid. The only other possibilities which have been mentioned are flywheels, solar cells and wind generators. It is not felt that these alternatives are available within the time span of this Act. Consequently, we feel the Committee may wish to reexamine this provision of the proposed Bill.

Returning again to the feasibility of producing 5,000 conversions in one year, we note that 4 out of 6 passenger conversions seen earlier this week were based on European chassis, while the other two were American. This may be due to the fact that very small cars are more frequently available from foreign manufacturers, or to the fact that such chassis are more readily available without power plant than are U.S. chassis, or possibly that the price is more attractive. In any event, we do have some small cars such as the Pinto, Vega and Gremlin which have been demonstrated with electric power, and we read that we can expect even smaller cars from Detroit next year . . . or at least from G.M., which will be introducing a "Chevette." In any event, the question of whether 5,000 conversions can be produced in one year without resorting to imported chassis probably should be looked into further.

The question of using conversions at all is one to which we gave considerable thought and ultimately arrived at an affirmative answer for two reasons. The first is that it would certainly be necessary to go this route in order to get the electric vehicle demonstration program going in one year, which is in itself a worthy objective. The second reason is that the conversion alternative will certainly keep the door open to small enterpreneurs with expertise and good ideas in the power train sector but a lack of manufacturing capability and capital for the production of chassis and bodies. In fact, some small companies, even with a contract in hand from ERDA may find it difficult to finance the fulfillment of such contract. It is suggested the Committee might consider some provision in the Act to assist such companies in their financing.

When we shift our thinking from the conversion to the "ground-up" car specifically designed for electric, some people visualize the industry taking a giant-step forward, bolstered by component research. I'd like to speak to that point for a moment, and also to what appears to be a paradox in the proposed Act; but which is not one, I believe.

The apparent paradox is that the Bill speaks on the one hand of demonstrating within a time-span of three years the commercial feasibility of electric vehicles and on the other hand, of promoting "basic research" on batteries, controls and motors. In its true sense, basic research cannot be expected to produce anything of commercial feasibility within three years. And yet it is necessary if we are to consider this Act as part of an on-going program which could lead to perhaps 25 million electric vehicles on the road in, say 15 years.

So the commercial feasibility which we shall see demonstrated will be of techniques and technologies which are currently operative. In particular, I'm thinking of that "portable source of electric energy," the lead-acid battery. All 18 of the vehicles here Tuesday were powered by such batteries, as are probably 99 and 44/100% of the approximately 100,000 battery-powered road vehicles in the world and a much greater number of industrial (off-road) vehicles.

The feasibility of H.R. 5470 depends, in other words, on the feasibility of the lead-acid battery. The demands of electric vehicles are different from those of i.c. autos, and the battery industry has been working on the problem of meeting these demands, with considerable progress over the past decade. We expect to see more refinements in the coming years. An important aspect of this type of battery is that it is cost-effective. It might be added that there is an abundant supply of lead, and that 80% of the lead used today is re-cycled.

The more compelling fact, however, is that over the time-span of this Act, there is no other battery. Speakers on transportation are often heard to say that electric vehicles won't get anywhere until we get a better battery. We don't need to debate that point in this arena. Suffice it to say that we can demonstrate the commercial feasibility of electric vehicles with present batteries and components, with no doubt some substantial improvements over the next 3 years as a result of the effects of this Act.

We would suggest that such basic research as is done on batteries under this Act should exclude lead-acid batteries, which don't need basic research. Instead, the money might be put to better use on some of the advanced power sources now in the laboratories to the end that their very promising energy output can be combined wih good cycle life, physical durability and safety and—above all—cost effectiveness. But lest we leave the impression that batteries are the only area for research, let me hasten to add that every single entity in the vehicle needs to be optimized, from the wall plug to the tires. Even if we were talking about i.c. vehicles rather than electrics, that would be true; for we have outlived the era of unlimited, cheap energy. We must now be living by that old precept, "Waste not, want not."

Perhaps this would be a good juncture to say something about the electric power industry, upon whom we will be relying when transporting becomes electric. There are some classic questions and I shall try to cover them. The first concerns the impact on the electric industry, should transportation go electric. There's a good deal of blue sky in long-term estimates, so let's take the one I mentioned a few minutes ago when I said, "let's suppose there could be 25 million electric road vehicles 15 years from now, namely, 1990. Based on estimates of total electric generation at that time, electric vehicle charging would take 2% of it. 100 million vehicles in the year 2000 might take as much as 5% of total generation. So availability doesn't look like much of a problem. And of course, if, as Congressman Mike McCormack pointed out, charging were done at night, no additional capacity would be needed.

Another question concerns pollution—wouldn't it, some people ask, just be transferred to the power plants? In this area, we can offer five points: (1) As pointed out in the Act, electric vehicles themselves produce no pollutants, so ground level pollution would be greatly reduced. (2) Emissions can more easily be controlled at power stations than in millions of individual gasoline engines. (3) Power plants are usually located away from high population densities. (4) Other than fossil fuels can be utilized, i.e., nuclear, hydro, geothermal. (5) Less fuel is required per passenger mile, therefore less total emission potential.

But as has been pointed out elsewhere, such questions might become academic if we have to do without gasoline. Speaking before an audience of energy planners in Ann Arbor on May 6, John J. Brogan of ERDA (as quoted in the NEW YORK TIMES, May 7) showed the audience a group of projections indicating exhaustion of U.S. domestic petroleum resources around the year 2000. Asked about the heavy emphasis on electric-powered transportation, Mr. Brogan said, "I don't think we have much choice."

An important provision of the proposed Act concerns, quote, "ascertaining consumer needs and desires so as to match the design of electric vehicles to their potential market." Unquote. I would say this is particularly applicable to auto body types and configurations. I mean, if people don't want to go to the supermarket in an open sports roadster which sits six or seven inches off the ground and has no storage space for packages, then we shouldn't try to give them one just because it's electric.

But on another front, namely performance, I think some kind of public education program may be needed to match consumer needs and desires to a vehicle which—on the one hand—has a great deal less power, speed and range than they desired, but—on the other hand—matches the driving missions which surveys indicate are most common. The Committee has rightly placed emphasis on, quote, "second cars, or as vehicles for short-range errands and commuting—applicable for most metropolitan areas in the United States." Unquote. A great deal of auto usage is of this nature, but it will most likely take a major public awareness campaign to convince people of the benefits of buying a car which will *only* meet those needs. For this is the nature of the electric car which we can expect to see during the time-span of this Bill; one of demonstrable commercial feasibility but nevertheless limited performance.

I'd like to conclude by complimenting the writers of this Bill for providing a program for the elimination of institutional barriers to the substitution of electrics for i.c. engine cars. It will take some study to just identify them. I can cite, without documentation, one state which charges a $15 extra charge on e.v.'s because they don't pay gasoline taxes; at least one state which won't register e.v.'s because they can't attain highway speeds; another which, at the manufacturer level, insists that an emission test be conducted on a highway at 50 miles an hour; and one requirement for a gasoline tank of a certain capacity and construction on every vehicle. I have purposely selected ironic examples but hasten to point out that such laws, where they exist, were not aimed at discriminating against electrics. They were just put on the books without considering that there might be such a thing ultimately. Perhaps the familiar prohibitions against discrimination because of age, sex, color, religion or place of national origin should have added to it, "or type of motive power."

Thank you for giving me this opportunity to present the views of the Electric Vehicle Council.

Mr. Campbell. Thank you, Mr. Chairman.

I have with me, in case we need to call on them, Mr. Norberg from the ESB, and Mr. Baker from the Lead Industries Association. Mr. Bry from Otis had to leave, and he is being represented by Mr. Lawry of Otis.

Mr. McCormack. Thank you very much.

Mr. Campbell. I would just like to start by thanking the chairman for his kind remarks about the Electric Vehicle Council's efforts on

Tuesday to bring vehicles here.

I will try to keep my remarks short.

I would like to mention that in the introduction to my paper in describing the Electric Vehicle Council I omitted to mention that the council sponsors the publication Electric Vehicle News, which I'm sure you're familiar with.

I'll just reiterate that we heartily endorse the bill and its goals, and compliment the committee on their foresight in proposing the development of electric vehicles now, while our depletion of petroleum reserves is still a few years off.

We also compliment the committee on the wording of the bill, and its thoroughness in covering the many considerations which will be involved.

We support the goal of putting 5,000 to 10,000 vehicles on the road in the next 3 years, and believe it's feasible.

We believe many worthwhile outcomes can be achieved by such a program, even though it is not likely that significant technological improvements could be achieved in that time, in 3 years.

We do feel that it would be well if the wording of the bill would specifically identify some long range goals beyond the life of the bill, especially with respect to the basic research, which would be part of the bill.

I think several people have mentioned the fact that we're really looking toward perhaps the end of the century, and I'm sure that the committee didn't intend this activity to just last 3 years, but that probably something could be said about the future.

There's been a good deal said about batteries, and certainly the energy source is a very significant item for consideration.

We would like to also emphasize the need to optimize all elements of the vehicle, and I think Dr. Thornton mentioned some of the other components, and I wouldn't even limit the consideration to that. That's one of the, shall I say, advantages of the so-called design "from the ground up" approach, that a vehicle can be optimized in every facet of its operation.

We feel it's very important to help create public awareness. When Dr. Kane spoke the other day, he said the main drawback to the introduction of electric vehicles was short life-cycle and high-life cycle costs. I don't think that those are the main drawbacks at all. The consumer doesn't know about those things. The main drawback is probably the low energy density of the sources and the relatively low performance of the vehicles compared with gasoline.

We agree with the Chairman and the committee that there are many missions that can be performed today with existing electric vehicles, and add that it would be necessary to "sell" that idea to the public. They, as I think has been said by others, don't just buy the vehicles for what they do with them. There is a little romance in the vehicle also.

We feel that it would be necessary to include in the program satellite subjects, such as training service people, and setting up charging stations, and attempting to eliminate legislative roadblocks where they may exist to the introduction of electric vehicles, and these are subjects that are mentioned somewhat in the bill, and I would strongly emphasize their importance.

Dr. Thornton mentioned the efficiency of electric as being the same as gasoline. This is one of a number of facts which is debated in the literature, and I would only like to say that the Otis people have developed some information on that. Dr. Salihi, an engineer at Otis, has written a paper on it, and I would like, at Mr. Lawry's suggestion, to put this into the record.

Mr. McCORMACK. If there's no objection, it will be inserted in the record at this point.

Mr. CAMPBELL. Thank you.

ELECTROBUS DIVISION, OTIS ELEVATOR CO., WILLIAM DAVID LAWRY, GENERAL MANAGER

Otis would like permission to submit published technical papers by Dr. Salihi & B. Borisoff indicating that:

(1) Electric vehicles go 1½ times as far as internal combustion vehicles on a gallon of petroleum.

(2) With 73 million electric cars in use by the year 2000, they would use less than 5 percent of the electric energy being produced at that time.

DR. JULAL SALIHI,
Project Director,
Otis Elevator Research Center.

WILLIAM LAWRY,
Manager of Engineering,
Otis Electrobus Division.

MR. B. BORISOFF,
General Manager,
Otis Electrobus Division.

Kilowatthours vs. liters

Gas buggies may be on the ropes by the Eighties if "super batteries" arrive on schedule

Long known only as golf carts and "go" carts, electric vehicles in increasing numbers are appearing in specialized intraurban applications—from industrial delivery to people-moving (both in buses and private automobiles). When operating at low speeds (under 60 km/h) and within a low acceleration range (to 50 km/h in at least 10 seconds), these lead-acid-battery-powered electric vehicles are significantly more efficient than their conventional gasoline-powered counterparts, but so far, they have been limited, in speed and range, by the lead-acid batteries presently available. This limitation may well be passé by the mid-1980s, assuming availability, in large quantities, of batteries with high power and energy densities by that time. As a result, the electric vehicle, with its already formidable assets, could well play an important role in vehicular transportation in the future.

But what of today's electrics? How good are they? The currently available limited-performance electric vehicle can reach typical cruising speeds of 65–80 km/h and is capable of accelerating from 0–50 km/h in 10–15 seconds. Its driving range, at maximum cruising speed, is typically 65–80 km, a figure that increases at reduced speeds. But determining precisely how today's electric vehicle compares to its gasoline-powered competitor is a somewhat more difficult task.

This author examined published test results of two different models of limited performance (lead acid battery powered) electric automobile prototypes—a 2100 kg model and a smaller "urban" car weighing 750 kg.

The overall specific energy consumption (see box on p. 63 for a precise definition of this term) for the two electric vehicles was calculated by considering each vehicle as part of an overall system including the electric power plant and transmission and distribution network (Fig. 1). Current nationwide efficiencies—35 percent in power generation and 91 percent in its transmission and distribution—were assumed. The calculation was based on published measured values of ac energy, fed to battery charger, multiplied by the above efficiencies of power generation and distribution. Overall specific energy consumption in the limited-performance electric vehicles, at different speeds, was plotted (Fig. 2). In the same figure, similar overall specific energy consumption curves for two gasoline-powered vehicles were plotted for comparison.

Gasoline car—fuel and energy consumed

Obviously, the energy consumption of conventional gasoline-powered cars can be used as a baseline, but the energy consumption for these cars varies widely, even in two identical model cars from the same manufacturer. Therefore, the baseline data must be derived by averaging measurements on a large number of cars. Results of such measurements have been available in terms of "fuel economy," expressed in km/liter, during the Federal Driving Cycle or at "constant cruise speed" (see box on p. 63). The data used were all for 1968–69 model cars.

Figures 3 and 4, plotted from the fuel economy data, show that, at low speeds and over the Federal Driving Cycle, specific fuel consumption (see box on p. 63) in 1/(km × kg) varies only slightly with vehicle weight. The variations are relatively higher at higher speeds, due, primarily, to the nonlinear variations in aerodynamic resistance with weight. The data of Figs. 3 and 4 are used as baseline for comparison of electric to gasoline vehicles. But a question immediately poses itself, and that is: how can a comparison be made between such different data—overall specific energy consumption, of electric vehicles against specific fuel consumption of their gasoline-powered counterparts? This can be done by considering the energy content of the burned fuel and converting the fuel consumption information to overall specific energy consumption.

Two actual gasoline vehicles—a 2100-kg conventional car, and a 610-kg, special purpose, "urban" car—were selected for comparison with their previously mentioned electric-powered counterparts. Similar to procedures carried out with the electric vehicles, overall specific energy consumption for the two gasoline cars was calculated by considering each vehicle as part of an overall system, including the refinery and gasoline transportation and distribution network (Fig. 5). The overall specific energy consumption is thus expressed in kWh/(km × kg) of crude oil fed to the refinery. For the 2100-kg car, this was obtained from the curves of Fig. 4, assuming 10-percent deterioration in fuel consumption associated with pollution devices of more recent, conventional gasoline cars, and a combined efficiency of 85 percent for refining, transporting, and distributing gasoline. Energy consumption values for the special-purpose urban car were obtained from published fuel economy data for the car, and by assuming the above efficiency for refining and distributing gasoline. It was further assumed that about 9.3 kWh of energy are contained in one liter of gasoline.

Comparing energy consumptions

In Fig. 2, overall specific energy consumption curves for two gasoline vehicles traveling at different speeds are included, in addition to electric vehicles curves. From the figure, it is clear that, at all speeds, the overall specific energy consumption of each gaso

Jalal T. Salihi Otis Elevator Co.

Useful terminology

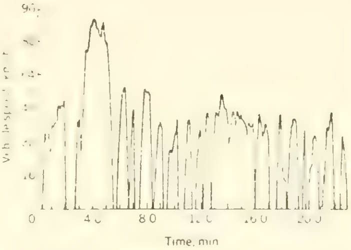
[illegible] specific energy consumption [illegible] used in [illegible] A [illegible] interesting fact [illegible] liters [illegible] per one kilogram of the [illegible] almost independent of vehicle weight (see Figs. 3 and 4 in the main text) [illegible] measure of energy-conversion efficiency.

Another useful criterion in analyzing vehicle efficiency is energy consumption—the energy consumed per unit distance (kWh/km) under specified conditions. From this term *specific energy consumption* is derived—the energy consumed per unit distance per unit weight of the vehicle, expressed in kWh/(km × kg).

A related term is *overall specific energy consumption*—the energy that has to be fed into a system per unit distance per unit weight of vehicle, in kWh/(km × kg). In the case of electric vehicles, this relates to energy of coal, or other fuels fed to the power plant. In gasoline vehicles it relates to energy of crude oil fed to the refinery.

In the calculations, *road energy* is used to refer to the total energy supplied to the wheels to overcome air drag and rolling resistances, as well as vehicle inertia during acceleration.

Again, the *average efficiency of electric car* is defined as the ratio of road energy per unit distance to ac energy supplied to battery charger, per unit distance. *Average overall system efficiency of an electric car* is defined as the ratio of road energy per unit distance to corresponding energy of coal or other fuel, per unit distance, fed into the electric power plant. Similarly, the *average efficiency of a gasoline car* is the ratio of road energy per unit distance to the corresponding energy in gasoline, consumed in the fuel tank per unit distance. And *average overall system efficiency of a gasoline car* is the ratio of road energy per unit distance to corresponding energy of crude oil fed to the refinery.



This precisely specified "Federal Driving Cycle" (FDC) includes accelerations, decelerations, and stops, over nearly 23 minutes. The cycle is currently used mostly in emission measurements, and it was derived from actual driving patterns encountered by Los Angeles suburbanites.

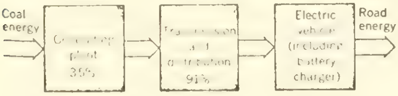
A fundamental measure in the evaluation of cars is their performance in specified driving cycles—the *Federal Driving Cycle* (FDC), for example. Currently used in emission measurements, FDC is derived from actual driving patterns encountered by Los Angeles suburbanites. The 'cycle' (see figure) has a precisely specified pattern of speed vs. time, including accelerations, decelerations, and stops, and it covers a total driving distance of approximately 12 km during a period of 1370 seconds. The aerage FDC speed is about 31.4 km/h. One other gage for assessment of car operation is its performance at *constant cruise* speed—namely, when the car is moving at a fixed speed (say, 80 km/h), experiencing no acceleration or deceleration.

line vehicle is considerably higher than that of its electric counterpart. For example, at 64 km/h, a ratio of 1.5:1 exists between the consumptions of the 2100-kg gasoline and electric vehicles.

From Fig. 2, it is also noted that the urban gasoline-powered car attains an optimum fuel economy of 31 km/l at 48 km/h. However, this car is only about half as efficient as an electric car of equal test weight moving at the same speed. It is further noted that the efficiency of the electric car increases as the speed decreases, while the efficiency of the gasoline-powered car deteriorates appreciably with declining speed.

In the previous analysis, overall specific energy consumption of gasoline-powered vehicles was derived from fuel economy data. A reverse process, related to electric vehicles, can also be very useful. That is, at a given overall specific energy consumption of an electric vehicle, what fuel economy is needed from a gasoline car of similar weight, to get the same consumption? To answer this question, data on energy consumption of two electric vehicles were compiled over "average" city and residential driving cycles (not the Federal Driving Cycle) and were computed in a manner similar to that used to obtain the electric vehicle consumption curves in Fig. 2. The results (Fig. 6) show that the overall specific energy consumption of limited-performance electric vehicles is almost independent of vehicle weight. The overall energy consumption is, therefore, nearly proportional to weight. In addition, it was concluded from Fig. 6 that a fuel economy of nearly 19 km/liter would be needed in a 906-kg gasoline vehicle to achieve the efficiency of an electric vehicle of similar weight, under the mentioned conditions.

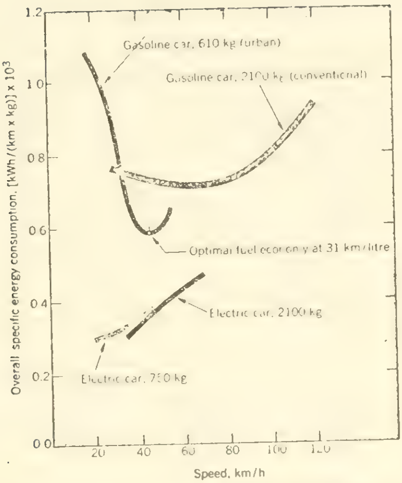
[1] Overall system representation of battery-powered electric vehicles, assuming current nationwide efficiencies—35 percent in power generation and 91 percent in its transmission and distribution in the U.S. Vehicle efficiency has not been included as it varies with driving mode for a specified vehicle.


Coal energy
Generating plant 35%
Transmission and distribution 91%
Electric vehicle (including battery charger)
Road energy

These data indicate that available electric vehicles are significantly more efficient than conventional gasoline-powered vehicles during both city driving and driving cycles involving low speeds and frequent stops.

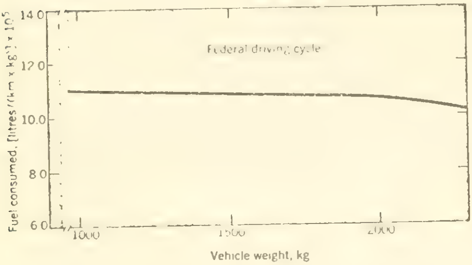
Future electric cars

The primary factors limiting the performance and range of the available electric vehicle are the low

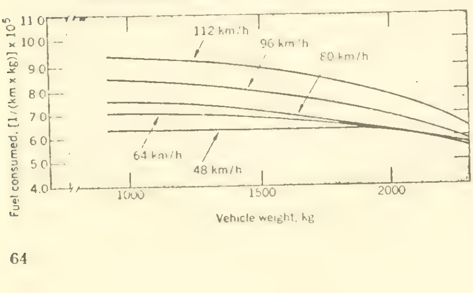


[2] Comparison of overall specific energy consumptions of lead-acid-battery-powered electric vehicles with those of gasoline-powered vehicles at constant cruise speeds. The weights shown are the vehicles' "test weights," a term that generally includes passenger and instrumentation weights, in addition to the vehicle's own "curb weight."

[3] Specific fuel consumption of conventional gasoline-powered cars, over the Federal Driving Cycle (see box on p. 63). The curve represents an average of data taken from over 170 cars, all 1968-69 models.



[4] Specific fuel consumption of conventional gasoline-powered cars at constant cruise speed (see box on p. 63). Average data from a large number of 1968 and 1969 model cars were used.



power and energy densities of current lead-acid batteries. These terms are usually defined as power (energy) per unit weight (not volume) of battery. Research has been underway to make batteries with improved characteristics. Energy density of 212 Wh/kg, about 6-7 times the values of present-day lead-acid batteries, and power density of 212 W/kg will be needed to provide, in future electric cars, the range, performance, and comfort (heating and air-conditioning, for example) available in present-day gasoline cars. Assuming the future availability of such batteries, energy consumptions and efficiencies of a high-performance electric car and a conventional gasoline-powered car can be compared.

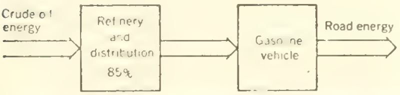
An exact analysis of the energy requirements for the future electric car over a given duty cycle requires knowledge of both the characteristics of each component in the vehicle's "power train" (for example, efficiency at different vehicle loads and speeds) and the values that will determine the maximum efficiency of the entire vehicle. The same is true for the conventional gasoline-powered car. However, such information for electric cars is not available, and, despite the long history and large population of gasoline-powered cars on the road, there is negligible data in the open literature regarding the full characterization of their components and their simulation on practical duty cycles. Therefore, it becomes necessary to assemble the widely scattered established data available on electric vehicles as well as conventional gasoline-powered cars, and then to interpolate those data, all the while eliminating unnecessary variables.

Heeding these guidelines, this author has posited a hypothetical electric car of the future that would weigh 1430 kg and would have body design and road losses similar to those of a conventional car of equal weight. Energy and power densities of 220 Wh and 220 W per kg and a combined charge-discharge efficiency of 72 percent are assumed for the battery of this reference car. The efficiency values assumed for the rest of the power-train components are achievable with current technology. The motor, it is assumed, would provide smoothly variable transmission without gear shifting and would power the rear wheels through a conventional differential including a fixed gear reduction to match the motor speed to the wheels.

To compute energy consumption, assume that maximum battery weight is limited to less than 25 percent of the total car weight. In the calculations, 113 kg, representing average additional passenger and luggage weight, must be added to the car weight.

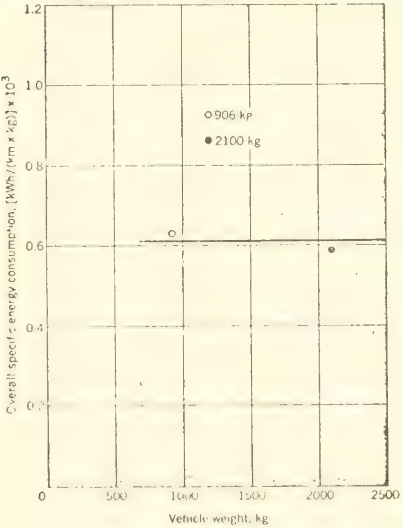
In Fig. 7, overall energy consumptions and efficiencies of the hypothetical electric car are depicted, along with comparable values for the baseline gasoline-powered car of the same weight and road energy (see box on p. 63). Since the operation of a passenger car is a mixture of the two driving modes used in Fig. 7 (that is, the Federal Driving Cycle and a constant speed of 112 km/h), the average of the two modes is employed as a basis for comparing energy consumptions and efficiencies. Using these average values (see the table that summarizes Fig. 7), we note that the hypothetical electric car of the future will consume about 72 percent of the energy required by its gasoline-using counterpart—1.32 kWh of coal fed to the power plant against 1.84 kWh of crude oil fed to the refinery for each kilometer of driving. And these results also indicate that the projected electric car will be more efficient than its gasoline competitor.

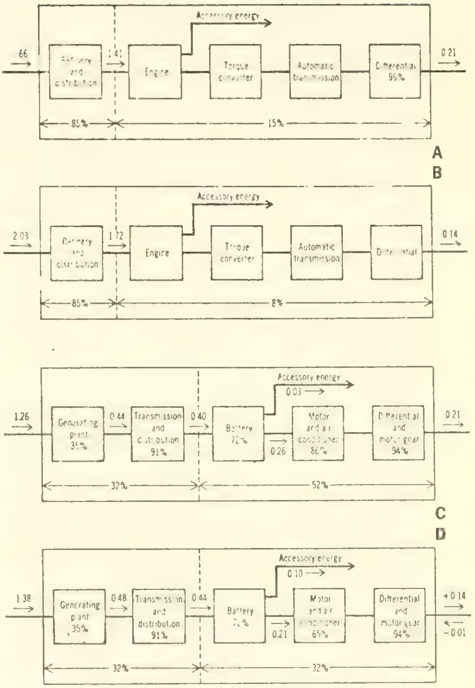
Despite the foregoing analysis, the final word has not yet been said about the efficiency of future electric cars. I have shown (see, the first reference in the "For further reading" box, p. 66) that by improving the aerodynamic design of the body, using more efficient tires, and better matching of power-train components, the energy consumption of the hypothetical electric car could be improved by 30 percent. Furthermore, I believe that a lighter-weight, optimized 906-kg electric car is the most likely type of future electric car, in view of energy and fuel saving requirements. In addition to its projected lower energy consumption (0.20 kWh against 0.42 in the 1430-kg hypothetical electric car, in ac-energy fed to battery charger, per km) this smaller, future electric car will also be more appropriate for residential charging, in



[5] Overall system representation of gasoline-powered vehicles, assuming 85 percent efficiency for refining, transportation, and distribution of gasoline. Vehicle efficiency has not been included as it varies with driving mode for a specified vehicle.

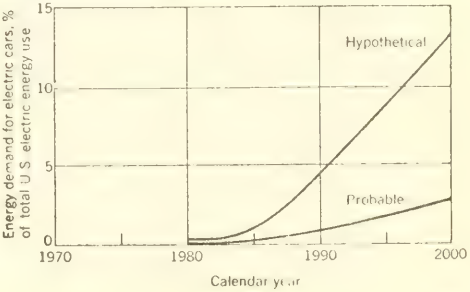
[6] Overall specific energy consumption of lead-acid-battery-powered electric vehicles during average city and residential driving cycles (not the Federal Driving Cycle). The weights shown are the vehicles' test weights (see Fig. 2 caption for an explanation of this term)





[7] Energy flow diagrams in a conventional, baseline, 1430-kg gasoline-powered car, and in a hypothetical, reference electric car of similar weight, body design, and road losses. All energy consumption levels per unit distance are expressed in kWh/km. Partial efficiencies of system components, indicated in percent, represent the ratio of average output to input energy per unit distance, in each component. A—Gasoline car at 112 km h; B—Gasoline car at Federal Driving Cycle; C—Electric car at 112 km h; D—Electric car at Federal Driving Cycle. The effect of energy regeneration during parts of the cycle is represented by 0.01-kWh/km reduction in road energy.

[8] Impact of widespread use of electric cars on total usage of electrical energy in the U.S.



view of charging limitations in residential electrical wiring systems.

Electrics' impact on energy demand

What impact will electric cars of the future have on energy demand from power generating plants? The answer depends on several factors beyond the energy consumption of electric cars themselves. These are the growth in electric car population, the average yearly mileage per car, and the increase in power generating capacity. I assume electrics will replace gasoline-powered cars gradually, and the rate will be mostly determined by the availability of practical high-energy density batteries that are not likely to be developed before 1980. Even if the technology for manufacturing such batteries is developed by then, an additional five years would be needed to produce these batteries in large quantities. Consequently, about five million electric cars are projected to be on the roads in the U.S. by 1985. In a hypothetical case, an extremely fast growth rate of the electric car population beyond that year will lead to about 150 million electrics by the year 2000. A more probable growth rate leads to about 72 million electric cars by the year 2000.

Assuming a yearly average driving distance of 16 000 km per car, and a gradual increase in energy usage leading to over 9000 billion kWh per year in the U.S. in the year 2000, the impact of electric cars on energy usage in the U.S. was plotted in two cases (Fig. 8). According to the probable assessment, 72 million electrics in the year 2000 (30 percent of the total estimated car population) with an energy consumption of 0.20 kWh/km per car (ac energy fed to battery chargers) would consume 2.5 percent of the total electric energy generated. However, even in a hypothetical worst case (150 million electrics consuming 0.42 kWh/km each), the impact will only be 11 percent.

◆

I. Energy requirements and overall system efficiencies for a hypothetical electric car and a baseline conventional gasoline-powered car, of identical weight (1430 kg) and structure, and having similar road loads

	Constant Cruise Speed (112 km/h)	Federal Driving Cycle	Average
Energy consumption and efficiency of cars			
Ac energy per unit distance, fed to battery charger of electric car, kWh/km	0.40	0.44	0.42
Heat energy per unit distance, of fuel in tank of gasoline, kWh/km	1.41	1.72	1.56
Efficiency of electric car, (%)	52.4	32.4	42.4
Efficiency of heat engine car, (%)	15	8.3	11.6
Overall system energy consumption and efficiency			
Heat energy per unit distance, in coal fed into electric power plant for the electric car, kWh/km	1.26	1.38	1.32
Heat energy per unit distance, in crude oil fed into refineries for gasoline car, kWh/km	1.66	2.03	1.84
Electric car system efficiency, (%)	16.7	10.3	13.5
Heat engine car system efficiency, (%)	12.7	7.1	9.9

For further reading:

Energy consumption data of a high-performance electric car and its impact on electric power generation and distribution systems were derived mainly from the paper "Energy requirements for electric cars and their impact on electric power generation and distribution systems," *IEEE Trans. on Industry Applications*, vol. IA-9, no. 5, pp. 516–[illegible], Sept./Oct. 1973, by the author. Specific fuel consumption data over the Federal Driving Cycle, shown in Fig. 3, were derived from the Environmental Protection Agency's (EPA's) Technical Report of the Office of Air and Water Programs, Nov. 1972, "Fuel economy and emission control." The constant-speed specific fuel consumption data of Fig. 4 were derived from *Consumer Reports* (pp. 33, 93, 153, 329, 359, and 544 in the [illegible] edition and pp. [illegible] and 325 in the 1969 edition). The overall specific energy consumptions of lead-acid battery-powered electric vehicles (Fig. 2 and 6) were computed from measured data on ac energy fed to the battery charger. The data for the 2100-kg electric car were derived from Report No. JV-2623-K-1 of Cornell Aeronautical Laboratory—"Technical Report on Mars II Electric Automobiles." The data for the 610-kg electric car in Fig. 2 were derived from SAE's paper No. 690461 of May 1969—"Special-purpose urban cars," by Gumbleton et al. The data for the 1430-kg electric car in Fig. 6 were derived from SAE's paper No. 720188 of Jan. 1972—"Sundancer: a test bed electric vehicle," by R. S. McKee et al. (More can be learned on this topic from p. 528 of the previously cited IEEE paper by the author.) The overall specific energy consumptions of gasoline cars (Fig. 2) were derived from published data on fuel economy. The data for the urban 610-kg gasoline car come from SAE's paper No. 690461 of May 1969, "Special-purpose urban cars," by Gumbleton et al., and for the 2100-kg conventional gasoline car from the specific fuel consumption data of Fig. 4.

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OVERALL PERFORMANCE & TRADE OFFS IN ELECTRIC BUS USAGE

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ABSTRACT

The Electrobus city transit bus has been operating in regular revenue urban transit service as well as demonstration services in several large cities in the United States and Canada, covering over 30,000 miles in the past 18 months.

From both the revenue and demonstration services, power and performance results have been gathered for typical urban center city bus operations. These results, detailed in this paper, verify that these electric buses obtain 7.4 - 13.5 miles per gallon of electric utility fuel, as compared to 3 - 6 and 5 - 8 miles per gallon from equivalent sized gasoline and diesel engine buses in similar service.

BUS DESCRIPTION

The Electrobus coach is a durable, low maintenance storage-battery powered electric bus used for short haul transportation. This type of bus has seen several successful historical applications such as that in Lyons, France.(1) Differing from the conventional diesel powered bus, this vehicle has low pollution levels and low noise emission. Compared to a trolley coach which obtains power from overhead wires, the battery powered electric bus is self-contained.

Battery powered electric buses thus provide the advantages of electric power without the mobility constraints of the overhead power system. However, because of battery energy and power and weight limitations, the electric bus must be carefully designed to meet the schedule and speed requirements of today's transit systems. The Electrobus transit vehicle was designed and performance tested to meet these criteria.

The Electrobus Model 20 is a 13,500 lb. curb weight, 25' long, nominally 21 seated passenger capacity bus. A larger version, the Model 26, is also available, at 14,300 lb. curb weight, 30' long with a nominal 30 seated passenger capacity. The same propulsion equipment is used for both models.

The bus is driven by a single, separately ventilated 50 HP, 72 volt DC traction motor, mounted under the floor ahead of the rear axle. The motor was specifically developed for this bus with a long, small diameter (14") frame to provide adequate road clearance with an unusually low floor height (22").

The application of motor power is controlled by low voltage electromechanical switching in an eight step contactor controller designed for maximum simplicity and reliability with quiet operation. A timed sequence of battery and motor field switching in response to power pedal position regulates motor power and speed. No transmission or clutch is used.

A single unit, 72 volt, 36 cell, 880 AH at 6h, 4,250 lb. lead acid storage battery is used for propulsion power. The battery is fitted with fork lift slots. Rapid battery exchange is aided by a quick disconnect feature, allowing full transfer in five minutes or less. Recharging is done on or off the bus by automatic charging equipment.

A separate 150 AH, 12 volt battery provides power for accessories and controller. This battery is recharged from the traction battery by a dynamotor, which also drives the motor cooling and coach body ventilation blower.

The foot controlled service brake initially reconnects the DC traction motor as a three phase AC generator to provide dynamic braking. Secondarily, the brake pedal applies air-assisted tandem hydraulic drum service brakes. Even if the air supply should fail completely, a mechanical override would still operate these service brakes. A separate, mechanically actuated disk parking brake is also furnished.

Dashboard instruments, in addition to the conventional speedometer and air pressure gauge, include a voltmeter, ammeter and battery condition meter.

Outside of the electric traction motor and controller, the electric bus running gear and mechanical components are standard heavy service truck and bus types.

The electric traction motor and control system are similar to trolley coach or railway types except for being designed for low voltage to suit storage battery operation rather than higher voltages as needed for distribution efficiency on wire fed, fixed power systems.

PERFORMANCE RESULTS

Long Beach Service

Regular daily scheduled electric bus service was inaugurated in Long Beach, California on August 12, 1974 using two Model 20 Electrobus coaches on a 6-1/2 mile cross town route.(2) 880 AH, 36 cell lead acid batteries were used.

The routing is over relatively level streets including principally medium traffic density built up residential areas, and a high traffic density central business district, averaging 6 - 10 stops per mile.

A third Model 20 is used for non-scheduled, charter, tripper and special runs.

Power consumption is monitored by submetering at the electric distribution panel serving the bus chargers, including relatively small amounts of power for lighting the charger installation and for charging the electric fork lift truck used for battery exchanging. The known route mileages were used to compute the average Kwh/mile bus power consumption.

For a typical three week period, the power consumption averaged 2.022 Kwh AC power/bus mile.

In a November 1974 published article reviewing the operation of their electric buses, the Long Beach Public Transportation Company commented favorably on passenger reaction and their operating experience, and also announced their plans for acquiring six more electric buses "...to give more service into downtown and to service other neighborhoods surrounding major shopping areas in Long Beach."(2)

Demonstrations

- Los Angeles - Southern California Rapid Transit District

A battery electric bus was demonstrated on a 10.3 mile SCRTD loop line in downtown Los Angeles. This service route has heavy business traffic, is signal-controlled at 90% of the intersections and has 75 posted on-demand passenger stops. Several significant grades are encountered, one a 10.3% climb. This test was comprised of four daily loops with an expected 3 hour service period. The Electrobus Model 20 with 72 volt, 650 AH Exide batteries was used.

On the first loop, 47 stops were made with the average time per stop being 25 seconds. Over the entire 5-1/4 hour service period, an average speed of 8 mph was maintained and average power consumed was 20 - 22 AH/route mile, equivalent to 2.64 Kwh/mile (AC power) based on an effective average battery discharge voltage of 68 volts, 70 battery and 80% charger efficiency.

On the 10.3% grade with a capacity 31 passenger load, 14 - 15 mph was maintained. After the demonstration, the alternative 880 AH battery was proposed for servicing this route on a 4 hour run, adequate power margin basis.

The driver and other SCRTD personnel observing were favorably impressed with the traffic handling of the electric bus. The passengers commented on the ease of entry, comfort and spaciousness of seating, and the smooth and quiet ride.

- Los Angeles Airportransit Service - International Airport

Four demonstration routes of somewhat lighter duty characteristics than the previously described city routes were included in these tests:

1) The non-stop trip from the Van Nuys Electrobus plant to LAX is 21 miles with one two mile, 6.5% grade. The Model 20 bus with 72 volt, 650 AH battery was used, carrying the equivalent weight of six passengers plus driver, due to the on-board charger (350 lbs.) and main charger (550 lbs.) being aboard. This trip was made in 38 minutes, with power and odometer readings being made for later airport test comparisons. The bus averaged 155 AH power consumption, 7.5 AH/mile or approximately 0.9 Kwh/mile AC power.

2) A 1.5 mile Interterminal Tram loop was a 6 mph scheduled speed route connecting the main airport parking lot and the terminals with seven posted passenger stops and an average of 5 - 12 various traffic stops. In two days of operations, the electric bus travelled 77 miles and made 47 loops. Consumption of power was 16 AH/mile (or 96 AH/h from the battery) with 8-1/2 average stops made per mile. At an average 68 volt battery discharge voltage and 70% battery, 80% charger efficiency, this was a 1.9 Kwh/mile AC input power consumption.

3) A 30 minute, 5.5 mile long loop connects the VSP parking area to the airline terminals. This route was serviced by the electric bus for three days, consisting of 32 round trips (185 miles total) and averaging 11 mph with 4 stops per mile. Power consumed was 11 AH/mile (121 AH/h from the battery) which was 1.36 Kwh/mile AC input.

4) A 30 minute, 3 mile long loop connects six of the terminals on the airfield side, with 6 - 8 stops per mile at 6 mph average speed. The electric bus serviced this route for one day, making 18 trips and covering 56 miles. The power consumed was 12AH/mile, (72 AH/h from the battery) which is 1.47 Kwh/miles AC input.

Passenger acceptance during all these services was considered outstanding.(3)

The foregoing operational data showed AC input power consumptions ranging from 1.47 to 2.64 Kwh/mile for multi-stop passenger service, or 0.9 Kwh/mile for a relatively continuous inter-community run (Van Nuys to Los Angeles International Airport), with 2.022 Kwh/mile having been measured over a three week period for the continuing Long Beach, California service.

EQUIVALENT FUEL CONSUMPTION

The operational performances and power consumptions described herein may be equated to the fuel consumption equivalent of the central power station supplying the battery chargers.

To make such a comparison meaningful in overall performance and energy consumption trade off terms, requires further consideration as to the impact of the particular fuels used, both as to grade for petroleum fuels, and as to alternative fuels where electric systems have mixed inputs, such as from oil or coal fired, nuclear, hydro or geothermal power plants.

For the purposes of this presentation, the benefits of electric generating plants use of lower grade fuels than usable by vehicle internal combustion engines is noted, but not further analyzed, as is also the apparent benefit of the typically remote, out of the central urban area locations of the electric generating stations.

Also, in the interest of simplicity, the following numerical comparisons will not differentiate between the use of oil and gas by electric power plants.

Then, for a modern station heat rate of 9,250 BTU/Kwh, bunker fuel of 151,000 BTU/gallons and a transmission efficiency of 90%, Kwh delivered per gallon fuel = .9 x 151,000 ÷ 9,250 = 14.7 Kwh/gallon.(4)

The following calculations will consider three classes of supply situations as applied to the range of 1.47 to 2.64 Kwh/mile as determined for typical multi-stop transit bus service.

For the hypothetical case of a large electric utility system obtaining all of its power from petroleum oil and derived gas, the measured electric bus power consumption would be equivalent to 5.5 - 10 bus miles per gallon of consumed central station fuel.

Actual electric utility systems depend on a variety of alternate power sources. The above case is considered unrealistically conservative and should be corrected for the actual mix encountered in present utility practice. For a specific utility (the Southern California Edison Company), the following power source present and projected data is given for 1975 (5) and 1980.(6)

Power Source	1975	1980
Non-Petroleum:		
Hydro Plants	8%	7%
Nuclear Plants	6%	14%
Coal Plants	12%	20%
Total:	26%	41%
Petroleum:		
Oil & Gas Total:	74%	59%

Based on the present day (1975) data, this mix results in equivalent mileages for Electrobus Model 20 operations of from 7.4 - 13.5 miles per gallon based on actual fossil fuel usage.

Since electric bus systems cannot be expected to reach full operational status in less than five years due to the necessity of scheduling, planning purchases, and the inevitable delays in placing large numbers of vehicles into service, it also appeared approptiate to consider the mix of power sources in 1980, rather than only the 1975 case. The electric bus mileage, corrected to these figures, will then result in electric bus operations being equivalent to a remaining petroleum fuel usage of from 9.3 - 16.9 miles per gallon.

SUMMARY AND CONCLUSIONS

The operation of storage battery powered electric buses, both in regular, continuing scheduled city transit service and in demonstration services in a number of cities in the United States, have demonstrated the practicality of this type of bus in a variety of urban and specialized conditions.

Power measurements taken on these runs have indicated a power consumption of from 1.47 to 2.64 Kwh/mile of regular passenger service. These measurements were based on the power used at the electric meter serving the battery charging equipment. To make it possible to derive comparative equivalent fuel usage for electric and engine driven buses, known modern electric power plant heat rates and a typical station to user's AC power panel transmission efficiency of 90% were used to compute the number of gallons of station fuel consumed due to the battery charging load.

This data shows that for the conservative case of 100% of the electric power being derived from the combustion of fossil fuels, the equivalent electric bus mileage is from 5-1/2 to 10 miles per gallon of power station fuel, pending on the nature of the route.

For the actual mix of petroleum and alternate fuels now experienced by a large typical public utility, oil and gas usage accounts for 74% of the total power, and the equivalent electric bus mileage in terms of petroleum fuel usage becomes 7.4 - 13.5 miles per gallon.

For the expected 1980 mix of petroleum and alternate fuels, oil and gas usage is projected to account for 59% of the total power, resulting in equivalent electric bus mileage of 9.3 - 16.9 miles per gallon.

Present day operating experience in city service for gasoline or diesel buses equivalent in passenger loading capacity to the Electrobus Model 20 used to gather the above information, shows that fuel consumption typically is in the order of 3 to 6 miles per gallon of gasoline, or 5 to 8 miles per gallon of diesel fuel. Since this fuel must be obtained by processing from crude petroleum fuels, and is not available from alternate sources to any significant degree, nor expected to be within the periods of our projection, these numbers clearly indicate the considerable energy savings benefits obtained from electric transportation by the use of the storage battery electric bus and its potential for alternative power sources.

This comparison neglects the additional possible benefits to the society due to the greater suitability of the large central power stations to effective air pollution and noise controls, compared to the limited potential for improvements on engines that must use their fuel at the point and time of use.

Other considerations favorable to the storage battery electric bus stem from the additional refinery losses and energy requirements needed to produce diesel fuel and gasoline.

REFERENCES

1. "Battery Buses in Lyons." Transport World, October 12, 1944, pp. 310 - 314.

2. "EV Dash Has Dashed Into the Hearts of the People of Long Beach." Electric Vehicle News, November 1974, pp. 10 - 13.

3. "Electrobus Makes Trial Run." Taxicab Management, January 1973, p. 27.

4. "Electrobus Trials, Long Beach & Mineola." Electric Vehicle Council, July 13, 1973.

5. "Monthly Financial and Operating Report to the Federal Power Commission." Southern California Edison Company, February 1975.

6. Telephone information from Laurel Parker and Ray Kulvicki, Southern California Edison Company, March 1975.

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Energy Requirements for Electric Cars and Their Impact on Electric Power Generation and Distribution Systems

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Abstract—Assuming the availability of a high energy and power density battery of 100 Wh/lb and 100 W/lb by the 1980's, the energy consumption and efficiency of electric and heat engine cars are compared on an equal basis. This is achieved by considering a reference electric car of 3150 lb weight similar in body construction, aerodynamics, and rolling resistance to a conventional heat engine car of equal weight, and comparing the performance of the two cars over the same driving modes. The reference electric car is then used as a baseline to evaluate the possible improvements in future electric cars. The energy consumption for an optimized 2000 lb electric car of driving range, comfort, and performance comparable to a conventional car is estimated. Assuming a gradual growth in electric car population leading to their widespread use by the 1990's, the impact on electric power generation and distribution systems is estimated. Although the analysis is based on a high energy and power density battery the results may be extrapolated to electric cars using lower performance batteries. It is noted that batteries with lower energy density can provide sufficient driving range to fulfill a significant portion of our transportation needs and their continued development and improvement will accelerate the achievement of the high energy-density goal [1].

INTRODUCTION

AT THE PRESENT time virtually all the energy requirements for transportation systems are met by petroleum and constitutes about 25 percent of the total national energy consumption. Within the transportation sector, the passenger car population is the major consumer of energy, accounting for more than half the total transportation energy [2].

The overall demand for energy including that for transportation has grown rapidly in the past and is continuing to grow. The present rate of energy consumption and its attendant pollution and the forecast for the future has reached a point where the environmental effects and the adequacy of resources to meet future demands need careful evaluation in order to provide measures for avoiding a possible future crisis.

In the last decade the pollution problem has been investigated by the Federal Government which resulted in issuing standards for emission controls from both stationary and mobile sources. More recently attention has been focused on the energy problem, and it is recognized that a unified approach is needed to solve both the energy and pollution problem simultaneously. To arrive at the most economical and viable solution, all possible future alternatives for generating power as well as the major consumers of power must be evaluated.

The transportation system and in particular the passenger car is a large consumer of energy and is therefore a major link in such evaluations and tradeoffs. This is particularly so with regard to pollution since the percentage of pollution attributable to passenger cars nationwide is significantly higher than the percent of energy that they consume. Also, the harmful health effects of the passenger car are high since by their very nature automobiles are mainly operated in densely populated areas.

The following criteria can be used to examine various alternative power systems for future passenger cars and to provide a basis for selection:

must complement the future mode of power generation for providing industrial, residential, and commercial requirements;
must be efficient;
must reduce pollution;
must not disturb the balance of resources and economy;
must be safe, quiet running, and adaptable to future transportation systems.

Electricity appears to be the most viable solution for satisfying the future demand for clean energy and can be derived from a variety of sources including nuclear, solar, and geothermal energy. The electric car is complementary to implementing this solution and provides means for conserving petroleum resources and decreasing United States dependence on foreign supply. The electric car appears, also, to meet the other requirements provided a practical high energy-density battery made of low-cost materials can be developed. Based on theoretical and practical considerations the development of such batteries is considered possible [1] and [3].

In spite of the potential advantages of electric propulsion for passenger cars, the efforts in developing the needed battery are negligible compared to the large sums of monies spent on improving heat engine cars. Some of the reasons for this are as follows.

1) Development of practical high energy-density batteries requires long term large investment with appreciable risk.

2) The automotive companies, the most logical industry to afford such risks, are now mainly involved in cleaning up the heat engines under pressure to meet the 1975–1976 standards on their present product line. Therefore, they can not be expected to put more than minimum effort on advanced batteries.

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The statements and opinions in this paper are those of the author.

The author is with the Advanced Automotive Power Systems Development Division, Environmental Protection Agency, Ann Arbor, Mich.

3) An electric car drawing [illegible] the auto industry must face formidable competition from mass produced heat engine cars which have been improved over more than 50 years of continuous development.

4) There is [illegible] pessimistic view regarding the validity of [illegible] and [illegible] their present impact on [illegible] generating plants. This view still prevails partly due to the lack of exact knowledge and information regarding the [illegible] requirements and the [illegible].

[illegible] data [illegible] electric [illegible] and to evaluate the future impact [illegible] the various elements of power generation and [illegible] distribution systems.

ASSUMPTIONS AND PROCEDURE

An exact analysis of the energy requirements for an electric car over a [illegible] utilization [illegible] components of the [illegible] the car with an only internal heat engine car [illegible] car is [illegible] available [illegible] literature [illegible] their components and their [illegible]. For an exact analysis [illegible] the car power systems is not presently possible.

The analysis in the [illegible] to give [illegible] estimates [illegible] by making [illegible] and interpretations [illegible] data [illegible] three types of electric cars [illegible] as follows with a reference car:

Electric Car (A): A [illegible] car of body design and [illegible] losses [illegible] conventional car [illegible] weight. A [illegible] 75 percent [illegible] for the battery [illegible] the power train [illegible] with current technology. [illegible] transmission [illegible] fixed gear reduction to [illegible] the wheels.

Electric Car (B): An [illegible] car with improved body structure to reduce [illegible] and rolling resistance and improved power train efficiency.

Electric Car (C): An [illegible] 2000-lb car similar to car (B) except for the lighter weight.

Due to the energy limitations of batteries and to reduce the impact of the electric car on the power generation and distribution systems it is [illegible] to minimize the energy consumption of electric cars. Moreover, future concern for saving energy and fuel may dictate a shift toward smaller cars. It is therefore, believed that the lighter weight optimized electric car (C) is more likely to be the type of future cars used. The reference electric car (A) is not a practical electric car. However, that car was included mainly in order to [illegible] and for purposes of comparison with conventional heat engine cars. It should be noted that the 3150 weight chosen for car (A) is representative of the mean weight of the present passenger car population and [illegible] between the weight of a full size luxury car [illegible] and a compact car (2000 lb). [illegible] the same [illegible] assumed. The [illegible] used [illegible] effect of drag [illegible] rolling resistance and other factors in reducing energy consumption in car (B) and car (C).

In [illegible] energy consumption of the electric [illegible] the following assumptions were made except [illegible] stated.

1) [illegible] battery [illegible] in the future (energy [illegible] power density [illegible] lb.)

2) [illegible] estimated to less than 25 [illegible]

3) The [illegible] energy [illegible] to overcome [illegible] rolling resistance [illegible] and to overcome vehicle [illegible] acceleration.

4) [illegible] percent [illegible] the corresponding [illegible] The average [illegible] of energy [illegible] road energy [illegible] to the [illegible] fuel [illegible] into the electric power generating plant.

5) The overall efficiency of the heat engine car is the ratio of [illegible] energy [illegible] consumed [illegible] car's fuel tank. The overall [illegible] efficiency [illegible] the ratio of road energy per mile to the corresponding heat energy [illegible] fed into the tank.

6) The specified weight [illegible] represent the curb weight. The energy calculations are based on the curb weight plus 250 lb.

ENERGY REQUIREMENTS FOR A REFERENCE ELECTRIC CAR OF 3150-LB WEIGHT AND BODY DESIGN, AERODYNAMIC, AND ROLLING RESISTANCE COMPARABLE TO A CONVENTIONAL CAR

The electric car is considered as a part of an overall system including the electric power generating plant and electric power transmission and distribution networks. The overall energy consumption is then expressed as heat energy in coal or other fossil fuel fed into the generating plant corresponding to 1 mi of travel.

The energy required to propel the electric car is determined by the energy consumed to overcome the aerodynamic and rolling resistance plus the energy consumed to overcome vehicle inertia during acceleration. Additional energy is required to provide for various accessories in the electric car and for heating and air conditioning. The corresponding energy that must ultimately be supplied by the electric generating plant is higher and is determined by applying the efficiency of various links involved in transforming the fuel energy to road energy and

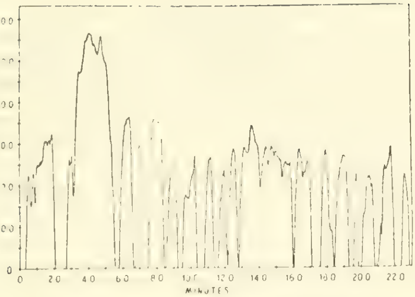

Fig. 1. Vehicle speed over Federal Driving Cycle.

the accessory energy. The efficiency figures are based on the weight distribution shown in Appendix I including a high energy-density battery of 750 lb. This battery weight which is 23 percent of total vehicle weight allows for passenger room and a luggage compartment comparable to a conventional car.

The overall driving pattern of a passenger car constitutes a mixture of various driving modes. The power train may be optimized to give the best efficiency for a selected driving mode which results in poor efficiency in other driving modes. In a practical car, however, the power train design is a compromise to give the best average efficiency for the overall vehicle operation. Therefore, a valid comparison of car perfor[illegible]ice using different propulsion systems must at least include [illegible] widely different representative driving modes. The two driving modes chosen in this investigation for estimating the energy requirements are first, the energy requirement to permit a normal highway cruise speed of 70 mi/h and second, the energy requirement over the Federal Driving Cycle.

The Federal Driving Cycle [4], currently used in emission measurements, is derived from actual driving patterns encountered by Los Angeles suburbanites. The speed profile for the Federal Driving Cycle is shown in Fig. 1. The cycle covers a total driving distance of approximately 7.5 mi over a total period of 1370 s. The average speed during this cycle is 19.6 mi/h.

Road Energy

The road load for the reference electric car is assumed to be equal to a conventional car of equal size. The same equations were, therefore, used for calculating the road load.

The road load at a constant cruise speed on a level road is the sum of the air drag and rolling resistances [5] and [6]. The air drag resistance is calculated from

$$R_d = \frac{P}{2g}\,(C_d\,A_f\,V^2)\ \text{lb}$$

where P is the air density in lb/ft^3 (0.0728 lb/ft^3 at 85°F), g is the gravitational acceleration in ft/s^2 (32.17 ft/s^2), C_d is the nondimensional drag coefficient, A_f is the frontal area in ft^2, and V is the vehicle velocity in ft/s

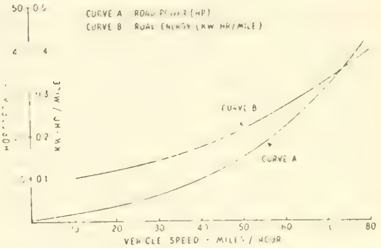

Fig. 2. Road power and energy delivered to wheels versus speed for passenger car of 3150-lb curb weight.

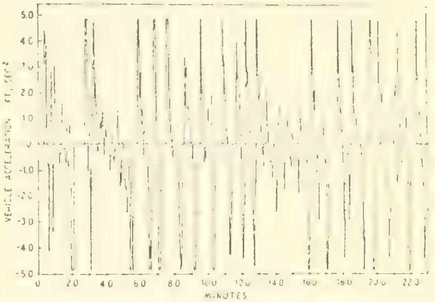

Fig. 3. Vehicle acceleration over Federal Driving Cycle

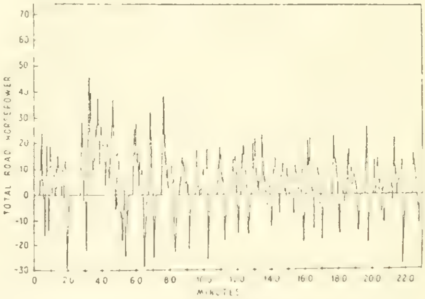

Fig. 4. Instantaneous power over Federal Driving Cycle delivered to the wheels of a passenger car of 3150-lb curb weight

The rolling resistance is calculated from

$$R_r = W/65\,[1 + (1.4 \times 10^{-3}\,V) + (1.2 \times 10^{-5}\,V^2)]\ \text{lb}$$

where V is the vehicle velocity in ft/s and W is the vehicle weight in lb.

Assuming $C_d\,A_f = 9$, the power required to overcome drag and rolling resistances and the corresponding energy were calculated and plotted in Fig. 2. From these data it is concluded that to maintain a vehicle speed of 70 mi/h, 32.30 hp is required to overcome the drag and rolling resistances. This corresponds to an energy consumption of (32.30 X 0.746)/70 = 0.34 kWh/mi. Similarly to maintain a vehicle speed of 55 mi/h, 18.8 hp is required which corresponds to an energy consumption of 0.25 kWh/mi.

A thorough analysis of the energy requirements over a driving cycle is very complex. An estimate of energy requirements can be derived from the following simplified analysis based on average considerations.

Figs. 3 and 4 show the instantaneous acceleration and the corresponding horsepower needed at the wheels during the Federal Driving Cycle. At any instant of time, the horsepower shown is the sum of horsepower required to overcome drag resistance, rolling resistance, and vehicle inertia during speed changes. The drag and rolling resistances used for determining the corresponding horsepower were computed from the equations shown previously. The horsepower associated with vehicle inertia was calculated from the acceleration and deceleration data shown in Fig. 3.

From Fig. 4 it can be seen that the instantaneous power during the driving cycle fluctuates continuously between positive and negative values. The average power was computed from the area under the curves divided by the total cycle time (1370 s) which gives an average positive power of 6.25 and a negative power of 1.79 hp. These correspond to an average positive energy of (6.25 X 0.746/19.6) = 0.23 kWh/mi and an average negative energy of (1.79 X 0.746/19.6) = 0.06 kWh/mi.

In a conventional heat engine car the negative energy is wasted mainly as heat in the brakes and other parts of the propulsion system. In an electric car, portions of this energy can be reused in regenerative braking.

Accurate analysis is not available for estimating the fraction of the negative energy that can be reused in an electric car. However, we do know that with regeneration the average energy required to drive the vehicle is reduced. It is assumed that only 1/3 of the negative energy is reused. Based on this assumption, the equivalent road energy consumed during a driving cycle is (0.23 - 0.06/3) = 0.21 kWh/mi.

Energy for Accessories, Heating, and Air Conditioning

Due to the energy limitations of batteries, it is necessary to minimize energy requirements for accessories. In the case of heating in cold weather, the use of a separate device has been proposed. However, for the sake of an equal comparison of a future electric car with a heat engine car, it is assumed that all accessory requirements are provided by the high energy-density battery.

It is assumed that the accessory power requirements (not including air conditioning and heating) constitutes an average power of 3 hp provided by the battery whenever the vehicle is in operation. In terms of energy requirements per mile, this is equivalent to:

0.032 kWh/mi for a 70 mi/h cruise speed;
0.11 kWh/mi for the Federal Driving Cycle.

The power requirements for air conditioning and heating fluctuate widely during the times when they are in use. Also, due to seasonal and regional variations in weather, they are only in use during part of the total yearly miles traveled. The yearly use factor (defined as miles when the device is in use per total yearly mileage traveled) varies nationwide due to regional variations in weather.

The propulsion system for the future electric car must be designed to accommodate peak air conditioning and heating power requirements of relatively short duration. However, in order to estimate the energy impact of heating and air conditioning on a nationwide energy demand, it becomes more meaningful to express these requirements on an average basis. Moreover, to account for seasonal variations, a yearly average must be used.

The initial power requirement for an air conditioner during a hot summer day may be as high as 6 hp for a short time. However, during the total times when the device is in use the average power is considerably less and is assumed to be 3 hp supplied by the battery. Assuming a nationwide use factor of 0.25, the average yearly power requirement supplied by the battery is 3 X 0.25 = 0.75 hp. In terms of energy requirement per vehicle mile, this is equivalent to:

0.008 kWh/mi for a 70 mi/h cruise speed;
0.027 kWh/mi for the Federal Driving Cycle.

Part of the heating can be derived from the heat rejection associated with the losses in the power train. For example, during a fixed cruise speed of 70 mi/h, a net power of 32.30 hp is delivered to the road from the battery at an efficiency of 64 percent corresponding to a heat rejection rate of about 13.6 kW. Similarly, during operation over the Federal Driving Cycle, an average power of about 6.5 hp is delivered to the road at an efficiency of 49 percent corresponding to a heat rejection rate of 5.0 kW (see Figs. 5 and 6). Part of the heat rejected can be used for heating the vehicle compartment. However, it appears that the heat rejection rate is not adequate for heating the vehicle. For the purposes of this investigation, it is assumed that the additional electrical power provided by the battery is 2.5 kW average during the total time when the heater is on. Assuming a nationwide use factor of 0.25, the average yearly power requirement supplied by the battery is 2.5 X 0.25 = 0.62 kW. In terms of energy requirement per vehicle mile this corresponds to:

0.009 kWh/mi for a 70 mi/h cruise speed;
0.031 kWh/mi for the Federal Driving Cycle.

In summary, assuming a widespread use of electric cars in the future, the average yearly energy in kWh/mi provided by the batteries for accessories, heating and air conditioning are estimated as follows.

	70 mi/h Cruise Speed	Federal Driving Cycle
Accessories	0.032	0.11
Air conditioning	0.008	0.027
Heating	0.009	0.031
Total	0.049	0.168

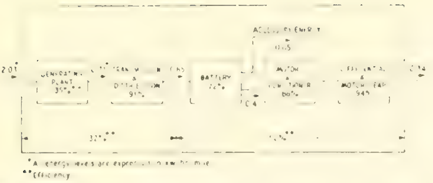

Fig. 5. Energy flow diagram at 70 mi/h for 3150-lb reference electric car of body design and road losses similar to a conventional heat engine car of equal weight.

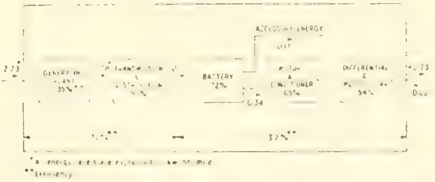
ACCESSORY ENERGY
0.17
2.23
GENERATING PLANT 35%**
TRANSMISSION & DISTRIBUTION
BATTERY 72%
0.34
MOTOR & CONTROLLER 65%
DIFFERENTIAL & MOTOR GEAR 94%
0.23
32%**
*All energy values are expressed in kWh per mile
**Efficiency

Fig. 6. Energy flow diagram over Federal Driving Cycle for 3150-lb reference electric car of body design and road losses similar to conventional heat engine car of equal weight.

TABLE I
EFFICIENCY AND ENERGY REQUIREMENTS AT 70-mi/h CONSTANT CRUISE SPEED FOR A 3150-lb REFERENCE ELECTRIC CAR OF BODY DESIGN AND ROAD LOSSES SIMILAR TO A CONVENTIONAL HEAT ENGINE CAR OF EQUAL WEIGHT

Heat energy in fuel fed into the power generating plant	2.03 kWh/mi (6940 Btu/mi)
AC energy fed into the battery charger	0.65 kWh/mi
Energy delivered by the battery after discharge comprised of road energy 0.42 kWh/mi, accessories 0.05 kWh/mi	0.47 kWh/mi
Road energy at wheels	0.34 kWh/mi
Efficiency of electric car (road energy/energy fed to charger)	52.4 percent
Overall system efficiency (road energy/heat energy in fuel fed into the generating plant)	16.7 percent

TABLE II
EFFICIENCY AND ENERGY REQUIREMENTS OVER THE FEDERAL DRIVING CYCLE FOR A 3150-lb REFERENCE ELECTRIC CAR OF BODY DESIGN AND ROAD LOSSES SIMILAR TO A CONVENTIONAL HEAT ENGINE CAR OF EQUAL WEIGHT

Heat energy in fuel fed into the power generating plant	2.23 kWh/mi (7620 Btu/mi)
AC energy fed into the battery charger	0.71 kWh/mi
Energy delivered by the battery after discharge comprised of road energy 0.34 kWh/mi, accessories 0.17 kWh/mi	0.51 kWh/mi
Road energy at wheels	0.23 kWh/mi
Efficiency of electric car (road energy/energy fed to charger)	32.4 percent
Overall system efficiency (road energy/heat energy in fuel fed into the generating plant	10.3 percent

Total Energy at 70 mi/h Cruise Speed

Fig. 5 shows the overall energy flow diagram for the reference 3150-lb electric car at a constant cruise speed of 70 mi/h, where all energy values are expressed in kWh/mi. These were obtained from the preceding road and accessory energies calculated and assumed efficiencies for each component of the power train, based on the backup data of Appendix II.

Table I summarizes the results of Fig. 5 and shows that the reference electric car, when operating at a constant cruise speed of 70 mi/h, consumes energy equal to 6940 Btu (2.03 kWh), in coal or other fuel fed into the generating plant per mile of driving. This corresponds to an energy of 0.65 kWh fed to the battery charger of the car. The car efficiency is 52.4 percent (charger input to road) and the system efficiency is 16.7 percent (generating plant input to road). The accessories including heating and air conditioning account for 10.6 percent of total consumption.

Referring to the backup data of Appendix II, it can be seen that the efficiency and energy consumption figures shown previously are on the conservative side and are achievable with current efficiency of electric power generations and distribution system and some modification of available motors and electric drive components. It is also noted that the combined charge-discharge efficiency assumed for the battery is 72 percent (assuming 80-percent efficiency at high discharge rates and 90-percent efficiency at slow overnight charge rates). This compares with a predicted combined charge-discharge efficiency of 81 percent for future high temperature alkaline-metal batteries [16].

Total Energy Over the Federal Driving Cycle

Fig. 6 shows the overall energy flow diagram and component efficiencies for the reference 3150-lb electric car over the Federal Driving Cycle. In this case, the average energy shown at each point represents the total energy over the entire driving cycle divided by the total distance in miles traveled during the cycle. Also, the efficiencies indicated for each component represents the ratio of the average output to input energy. The effect of regeneration on energy consumption is represented by an equivalent reduction in road energy from 0.23 kWh/mi without regeneration to 0.21 kWh/mi.

Table II summarizes the results of Fig. 6 and shows that the reference electric car, when operating over the Federal Driving Cycle consumes energy equal to 7620 Btu (2.23 kWh) in coal or other fuel fed into the generating plant per mile of driving. This corresponds to an energy of 0.71 kWh/mi fed into the battery charger of the car. The car efficiency is 32.4 percent (charger input to road) and the system efficiency is 10.3 percent (generating plant input to road). The accessories, including heating and air conditioning account for 33 percent of total energy consumption.

It is noted that the energy consumption of 0.71 kWh/mi (comprising of 0.47 kWh/mi for road and 0.24 kWh/mi for accessories) compares with an energy consumption of 0.50 kWh/mi for a limited performance electric car of equal weight determined from the measured data of Appendix II. The energy for each of the two cars is based on different driving cycles and are not directly related, however, they appear to indicate that the estimated consumption for the reference electric car are conservative estimates and are on the high side. The higher values are partly due to the lower motor efficiency (since no gear shifting was assumed) and the high value of accessory energy assumed for the reference electric car. Also referring to the backup data of Appendix II, it can be seen that the effienergy values assumed for the power train components of the reference electric car seem to be on the conservative side and are easily achievable with today's technology.

ENERGY REQUIREMENTS FOR A BASELINE CONVENTIONAL HEAT ENGINE CAR OF 3150-LB WEIGHT

The heat engine car is considered as a part of an overall system including the refinery. The overall energy consumption is thus expressed as heat energy in crude oil fed into the refinery corresponding to 1 mi of driving. This energy is determined next for both cases of a 70 mi/h constant cruise speed and for the Federal Driving Cycle.

The input energy to the car alone was determined from available fuel consumption data, while the road energy is assumed to be the same as that calculated for the reference electric car of equal weight. Knowing the input and output energy, efficiency values were assigned to the individual power train components. The overall energy requirement is the energy supplied to the car plus the loss in the refinery. The backup data for the energy consumptions and efficiency figures used are given in Appendix III.

There is a lack of data on fuel consumption, and the only set of consistent consumption data for the Federal Driving Cycle and constant cruise speed available to the author are those in [7] and [8]. [illegible] the energy consumption for both [illegible] is taken as the average of a large number of 1975-[illegible] as shown in Appendix III. [illegible] the baseline heat engine car [illegible] 10 percent lower to allow for expected [illegible] from meeting the 1975-1976 emission standards [illegible] a wide difference in opinion regarding the [illegible] ranging from 10-20 percent. The lower [illegible] in this paper is, therefore, favorable to the conventional car.

Total Energy at 70 mi/h Cruise Speed

Fig. 7 shows the overall energy flow diagram and component efficiencies for the 3150-lb baseline heat engine car operating at a constant cruise speed of 70 mi/h, where all energy values are expressed in kWh/mi.

Table III summarizes the results of Fig. 7 and shows that the heat engine car, when operating at a constant cruise speed of 70 mi/h, consumes energy equal to 9130 Btu (2.67 kWh) in crude oil fed into the refinery per mile of driving. This corresponds to an energy of 7700 Btu/mi (2.27 kWh/mi) provided by gasoline in the fuel tank of the car. The car efficiency is 15 percent (fuel tank to road) and the system efficiency is 12.7 percent (refinery input to road).

Total Energy Over the Federal Driving Cycle

Fig. 8 shows the overall average energy flow diagram and efficiency for the Federal Driving Cycle. The efficiencies of intermediate links are not shown since there are no adequate data available for obtaining these over the Federal Driving Cycle.

Table IV summarizes the results of Fig. 8 and shows that the heat engine car, when operating over the Federal Driving Cycle, consumes energy equal to 11100 Btu (3.26 kWh) in crude oil fed into the refinery per mile of driving. This corresponds to an energy of 9450 Btu/mi (2.77 kWh/mi) provided by gasoline in the fuel tank. The car efficiency is 8.3 percent and the system efficiency is 7.1 percent.

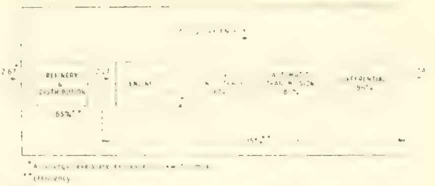

Fig. 7. Energy flow diagram at 70 mi/h for 3150-lb baseline conventional heat engine car.

TABLE III
EFFICIENCY AND ENERGY REQUIREMENTS FOR A 3150-LB BASELINE CONVENTIONAL HEAT ENGINE CAR AT 70 MI/H CONSTANT CRUISE SPEED

Heat energy in crude oil fed into the refinery	2.67 kWh/mi 9130 Btu/mi
Heat energy consumed in gasoline of fuel tank	2.27 kWh/mi 7700 Btu/mi
Energy delivered to torque converter	0.43 kWh/mi
Road energy at wheels	0.34 kWh/mi
Efficiency of heat engine car (road energy/energy contained in gasoline)	15 percent
Overall system efficiency (road energy/heat energy in crude oil)	12.7 percent

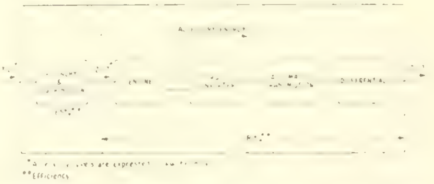

Fig. 8. Energy flow diagram over Federal Driving Cycle for 3150-lb baseline conventional heat engine car.

TABLE IV
EFFICIENCY AND ENERGY REQUIREMENTS FOR A 3150-LB BASELINE CONVENTIONAL HEAT ENGINE CAR OVER THE FEDERAL DRIVING CYCLE

Heat energy in crude oil fed into the refinery	3.26 kWh/mi 11 100 Btu/mi
Heat energy consumed in gasoline of fuel tank	2.77 kWh/mi 9 450 Btu/mi
Road energy at wheels	0.23 kWh/mi
Average efficiency of heat engine car (road energy/energy contained in gasoline)	8.3 percent
Overall average system efficiency (road energy/heat energy in crude oil)	7.1 percent

COMPARISON OF ELECTRIC AND HEAT ENGINE CAR

Energy Requirement

A summary of the energy requirements and efficiency for the two cars and the corresponding overall system requirements is shown in Table V where all energy consumptions are expressed in kWh/mi.

TABLE V

	70 mi/h	Federal urban cycle	Average
Car Consumption and Efficiency			
AC energy fed to the battery charger of electric car	0.65	0.71	0.68
Heat energy in gasoline of fuel tank for heat engine car	2.27	2.77	2.52
Efficiency of electric car (percent)	52.4	32.4	42.4
Efficiency of heat engine car (percent)	15	8.3	11.6
Overall System Consumption and Efficiency			
Heat energy in coal fed into the electric power generating plant for the electric car	2.03	2.23	2.13
Heat energy in crude oil fed into the refineries for heat engine car	2.67	3.26	2.96
Electric car system efficiency (percent)	16.7	10.3	13.5
Heat engine car system efficiency (percent)	12.7	7.1	9.9

Since the operation of a passenger car is a mixture of the two driving modes, the last column which is the average energy consumption of the two modes, is used as a basis for comparison. This shows that the reference electric car has a significantly higher efficiency than the conventional heat engine car of equal size. The overall energy requirement for the electric car is about 72 percent of the heat engine car.

Driving Range

Despite the higher efficiency and lower energy requirement shown previously, the reference electric car is not practical since it does not provide an acceptable driving range due to the energy storage and size limitations of the battery.

For an energy density of 100 Wh/lb and a battery weight of 750 lb, the total energy available at the battery terminal is 75 kWh. The driving range for the reference electric car corresponding to a constant cruise speed of 55 and 70 mi/h are shown as follows.

	55 mi/h	70 mi/h
Total average energy required at battery terminal including accessories for the cruise condition	[illegible] kWh/mi	0.47 kWh/mi
Maximum driving range	[illegible] mi	160 mi

To increase the driving range, it is necessary to reduce the energy requirement of the electric car. The various factors affecting energy will be discussed in the following section.

ENERGY REQUIREMENTS FOR THE IMPROVED ELECTRIC CAR OF 3150-lb WEIGHT

The drag and rolling resistances of the electric and heat engine cars can be reduced appreciably by an improved aerodynamic design of the body, and [illegible] tire characteristics. Further savings in energy [illegible] efficiency and better [illegible] of the power train components. Also the accessory load, especially at low speeds of urban driving cycles, constitutes a significant portion of the total energy consumed. Reduction in this load has a marked influence on consumption.

The factors influencing the energy consumption can thus be divided into three classifications: 1) [illegible] power train components [illegible] gearing; 2) air drag and rolling resistances which are associated mainly with the weight and design of the body of the car and tire characteristics, and 3) energy requirements for accessories.

The effect of each of these factors on energy consumption and their total effect in reducing the energy consumption of the reference 3150-lb electric car are discussed next. It is noted that the weight calculation of the reference car is shown in Appendix I, which includes a 750-lb battery with a combined charge-discharge efficiency of 72 percent.

Efficiency of Power Train Components

Some projected improvements in component efficiency and the effect of gear ratio on efficiency are discussed in Appendix II. This shows that the efficiency [illegible] energy consumption assumed for the reference electric car are [illegible] standards. [illegible] power generation and distribution [illegible] of available energy [illegible] the car [illegible]. By incorporating an optimized gear [illegible] motor and [illegible] at low speed [illegible] efficiency [illegible] the motor and associated [illegible] increased from 65 percent [illegible] car to 76 percent. Moreover [illegible] effect of regeneration. However [illegible] improvement in high speed cruise efficiency [illegible] 80 percent is expected.

The combined charge-discharge efficiency of 72 percent assumed for the battery [illegible] comparable to what may be achieved [illegible] Appendix II [illegible] 72 percent is used.

Air Drag and Rolling Resistance

The effect of improved aerodynamic and body design [illegible] summarized in [illegible] of Fig. 8 shows that the [illegible] 70 [illegible]

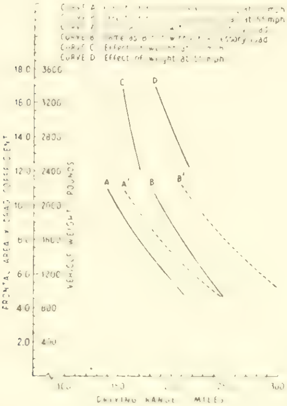

Fig. 9. Effect of drag coefficient, frontal area, weight, and accessory loads on driving range of electric cars.

B_1 shows the same as A except that the cruise speed is 55 mi/h instead of 70 mi/h. Curve C, shows the effect of variations in vehicle weight on driving range for a fixed cruise speed of 70 mi/h and a fixed value of $C_d A_f$ = 9. Curve D, shows the same as C except that the cruise speed is 55 mi/h instead of 70 mi/h. From these curves it can be seen that by reducing $C_d A_f$ from 9 to 6 the driving range at 70 mi/h can be increased from 160 to 190 mi (19 percent reduction in energy consumption). Similarly the driving range at 55 mi/h can be increased from 203 to 237 mi (14 percent reduction in energy consumption). The curves also show the effect of using lightweight structures on the driving range which is relatively small at high speeds. It is noted, however, that weight reduction would permit an equivalent increase in battery weight with an attendant increase in driving range. Special tire design can reduce the rolling resistance by as much as 50 percent and is very desirable for electric cars.

A detailed analysis of various factors affecting the road load is given in [9]. The analysis indicates that in an optimized car, it may be possible to reduce the road energy consumption associated with air drag and rolling resistances by 45 percent at a constant cruise speed of 50 mi/h. Similarly for the specific city driving route considered, a reduction in energy consumption of 25 percent is [illegible].

Note that the city driving route mentioned previously is not the same as the Federal Driving Cycle used in this paper. Also the cruise speed of 50 mi/h mentioned previously compares with 70 mi/h used in this paper; however, due to the nonlinear relationship between air drag losses and speed, the effect of optimizing the aerodynamic design is more profound at 70 mi/h compared to 50 mi/h.

Accessory Energy

The accessory energy for the reference electric car over the Federal Driving Cycle is about 33 percent of the total energy consumed (see Fig. 6). Also, the marked effect of accessory energy at higher speed can be seen from the dotted curves of Fig. 9, where curve A' shows the same relationship as curve A, but without accessories, and curve B' shows the same relationship as curve B, but without accessories.

It is, therefore, necessary to optimize the efficiencies of accessory components. One of the advantages of electric cars compared to heat engine cars is that most of the accessory loads can be completely disconnected while the vehicle is stationary and that the accessory power can be easily programmed. This will further improve the efficiency of electric cars at low speeds during city and metropolitan driving conditions.

Total Reduction in Energy Consumption

The combined effect of the preceding improvements is summarized in Table VI, and compared with the energy consumption of the baseline heat engine car and the reference electric car. The results indicate that the combined improvements, if achieved, can result in a 3150-lb electric car with an energy consumption of 1.08 kWh/mi, which is only 37 percent of the energy consumption of the baseline heat engine car and 5[illegible] percent of the energy consumption of the reference electric car.

It is noted that the possibility of achieving the predicted efficiency of 81 percent in a practical battery requires some technical breakthroughs, and its attainment in the near future is one of the uncertain factors in the preceding discussion. Without this improvement, that is assuming a combined charge–discharge efficiency of 72 percent, the effect of the preceding improvements would reduce the energy consumption of the electric car to 1.[illegible]8 kWh/mi which is 42 percent of the energy consumption of the baseline heat engine car and 58 percent of the energy consumption of the reference electric car. A reduction in the energy consumption [illegible] does not involve any breakthroughs and appears to require only advanced development. It is not known, however, [illegible] the degree of improvements that can be achieved when imposed by the need for safety, the desire for comfort, and by practical and economic considerations. To verify the practicality of the lower limits specified, a thorough analysis including safety and comfort considerations is needed.

Due to these uncertainties a conservative overall energy consumption of only 1.55 kWh/mi is assumed to be practically achievable in an optimized high performance future electric car of 3150 lb weight, which corresponds to an ac energy of 0.49 kWh/mi fed to the battery charger of the electric car. These conservative consumptions will be used in the following section for estimating the energy consumption of an optimized 2000-lb electric car. Note that the assumed energy consumption is 52 percent of the energy consumption of the baseline heat engine car and 73 percent of the reference electric car.

Energy Requirements for an Optimized Electric Car of 2000-lb Weight

The relationship between weight and energy consumption of passenger cars is discussed in Appendix III. The results indicate that the specific energy consumption over a driving cycle and at low speeds, expressed in gallons per mile per pound, is approximately independent of weight and varies by less than 5 percent for a change in vehicle weight from 2000 to 3150 lb. The corresponding variation at a constant cruise speed of 70 mi/h is higher and is less than 10 percent. Therefore, within

TABLE VI
EFFECT OF OPTIMIZATION ON ENERGY CONSUMPTION OF ELECTRIC CARS OF 3150-LB CURB WEIGHT[a]

	Car Consumption (AC Energy Fed to Battery Charger, kWh/mi)			Overall Energy Consumption (Heat Energy, kWh/mi)			Ratio of Overall Energy Consumption to That of Gasoline Heat Engine Car[b]
	70 mi/h	Federal Cycle	Average	70 mi/h	Federal Cycle	Average	
A. Reference electric car (3150 lb)	0.65	0.71	0.68	2.03	2.23	2.13	0.72
B. Electric car with gear shift	0.65	0.64	0.645	2.03	2.01	2.02	0.68
C. Electric car with gear shift and reduced road losses (45-percent reduction at 70 mi/h and 25-percent reduction over Federal cycle)	0.39	0.54	0.465	1.22	1.70	1.46	0.49
D. Electric car with gear shift, reduced road losses, and 50-percent reduction in accessory energy	0.35	0.43	0.39	1.10	1.36	1.23	0.42
E. Same as D plus an improved battery of 81-percent combined charge–discharge efficiency	0.31	0.38	0.345	0.97	1.19	1.08	0.37

[a] Assuming a battery weight of 750 lb (23 percent of total vehicle weight) with an energy density of 100 Wh/lb.
[b] The overall energy consumption for the 3150-lb gasoline heat engine car is 2.96 kWh/mi (energy in crude oil).

this weight range, the actual energy consumption is roughly proportional to weight. The same relationship appears to be true for electric cars (see Appendix II).

Based on this conclusion, the energy consumption for an optimized electric car of 2000-lb curb weight and of performance and comfort comparable to a conventional car is 0.49 (2000 + 250)/(3150 + 250) = 0.32 kWh/mi. This is the average ac energy supplied to the battery charger corresponding to 1 mi of driving.

Assuming an efficiency of 35 percent for electric power plant and 91 percent for transmission and distribution, the corresponding energy in coal or other fuels fed into the electric power generating plant is 1.01 kWh/mi.

This compares with an energy consumption of 1.71 kWh/mi provided by gasoline for a conventional heat engine car of equal weight (see Appendix III). Assuming an efficiency of 85 percent for refining and distributing gasoline, it can be concluded that the overall energy requirement for an optimized electric car is only half the overall energy requirement for a conventional car of equal weight.

EFFECT OF BATTERY CHARACTERISTICS

The analysis in this paper were based on a high energy and power density battery (100 Wh/lb and 100 W/lb) expected to be available in the future [1]. The results, however, can be extended to lower performance batteries. For example, the results of Table VI show that a 3150-lb electric car with automatic gear shift and minimized air drag and rolling resistance requires 0.39 kWh/mi of ac energy fed to the battery charger during constant cruise speed of 70 mi/h. This corresponds to an energy of 0.28 kWh/mi delivered at the battery terminal (assuming a combined charge–discharge efficiency of 72 percent). A high energy-density battery of 750 lb (comprising 23 percent of total vehicle weight) can store 75 kWh and can therefore, provide a driving range of 75/0.28 = 268 mi. Using a battery of equal weight and efficiency but with a lower energy density of 50 Wh/lb reduces the driving range to 134 mi. To increase the driving range to 200 mi with this battery the battery weight must be increased from 750 to 1120 lb. The new battery weight would then be about 30 percent of the total vehicle weight.

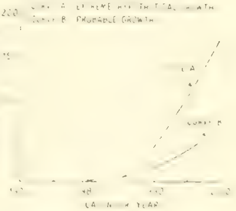

Fig. 10. Assumed growth in electric car population.

IMPACT OF ELECTRIC CARS ON ELECTRIC POWER GENERATION AND DISTRIBUTION SYSTEM

The impact of electric cars on electric power generation and distribution systems depends on the characteristics of the future electric cars, the growth in the electric car population, the miles traveled, and the growth in the generating capacity of future generating plants.

It is assumed that electric cars will replace heat engine cars gradually and that the timing of this change will be determined mainly by the availability of practical high energy-density batteries. The projected data shown in Fig. 10 indicate an electric car population of 0.5 million in 1980 and of 5 million on United States roads by 1985. Because practical high energy-density batteries are not likely to be developed before 1980, the small number of cars shown for that time are assumed to be limited performance cars. Even if the technology for manufacturing such batteries is developed by then, an additional five years would be needed to produce these batteries in large quantities; consequently, 5 million cars are shown by 1985. Curve *A* shows a hypothetical case assuming an ex-

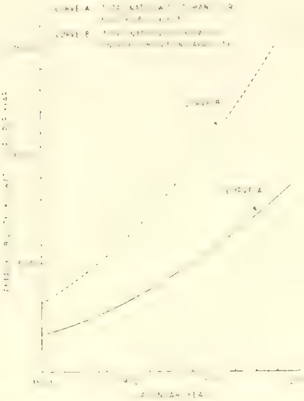

Fig. 11. Projected electrical energy demand and capacity in United States.

supply [illegible] 1990 [illegible] by the year 2000 [illegible] all [illegible] the car population. [illegible] be experienced, however, [illegible] due to the "worst case" [illegible] on power generation. [illegible] the year 2000 [illegible].

The projected [illegible] electric energy in the United States is shown in Fig. 11. Curve A represents the average annual [illegible] for the year 2000. The dashed curve B represents the [illegible] peak [illegible] capacity [10] and [11].

[illegible] 2000 [illegible] to the battery charger from the outlet.

Impact on Nationwide Demand from Electric Power Generating Plants

Assuming a yearly driven distance of 10 000 mi per car, the total yearly nationwide energy demand for future electric car population was calculated for the following two conditions.

1) For a hypothetical condition [illegible] extreme growth rate in electric car population leading to the total replacement of the heat engine car by the year 2000 (Fig. 10, curve A), and an energy consumption of 0.68 kWh/mi corresponding to an electric car population of average weight and characteristics similar to today's conventional car.

2) For a more probable condition [illegible] growth rate replacing 40 percent of the heat engine cars by the year 2000 (Fig. 10, curve B) and an energy consumption of 0.32 kWh/mi corresponding to an optimized electric car population (2000-lb average weight).

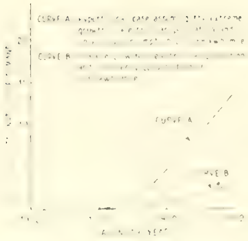

Fig. 12. Impact of widespread use of electric cars on nationwide demand from electric power generating plants.

The results for these two conditions are shown in Fig. 12 which clearly indicates that the additional energy [illegible] electric cars is [illegible] compared with the [illegible] total [illegible] for electric energy. [illegible] 2000 [illegible] is only 2.4 percent of the total nationwide demand. Even for the extremely hypothetical condition [illegible] the percent is only 14 percent.

Impact on Residential Distribution Networks and Energy Consumption

Considerable improvement in the residential distribution system is required to accommodate the anticipated growth in the electric car population. However, there appears to be no [illegible] for a gradual build-up of electric cars [illegible] of the distribution network is [illegible] by the utilities. In fact, as [illegible] later, the energy requirement of electric cars in the [illegible] park [illegible] the summer months [illegible]. It should be emphasized, however, that the maximum battery charge rate of electric cars from household meters must be limited to acceptable levels (for example, not to exceed [illegible] kW), and presently there is no practical way foreseeable for achievement of fast charging in residential areas.

The following example will bring the energy and power demands for electric cars, when supplied solely from household meters, into perspective with current and future household energy and power requirements.

> Based on an acceptable national daily driving distance of 27 mi per car (10 000 mi per year), the average daily energy required for charging the battery of the reference 3150-lb car is 0.68 × 27 = 18.36 kWh. This energy can be provided in 8 h at a constant power level of 2.29 kW or in 4 h at a constant power level of 4.58 kW. Similarly the energy required for the 2000-lb optimized electric car is 0.32 × 27 = 8.64 kWh. This energy can be pro-

vided in 8 h at a constant power level of about 1 kW or in 4 h at a constant power level of about 2 kW. For comparison, a residential house of 2400 ft^2 living area when adequately air conditioned requires a 5-ton air conditioner driven by a 5-hp motor (about 4 kW). The motor in a normal summer day will operate at an average power level of 1.5 kW, and may require a daily energy comparable to the average daily requirement of an electric car.

The maximum impact of electric cars occurs when charging a fully discharged battery. The storage capacity of the battery for the reference electric car is 750 lb × 100 Wh/lb = 75 kWh. To provide this energy to a fully discharged battery at combined charge–dischage efficiency of 72 percent the house meter must provide a continuous power of 8.6 kW over a 12-h charging period or a continuous power about 13.0 kW over an 8-h charging period. Similarly, the storage capacity of the battery for the optimized 2000-lb electric car is 460 × 100 Wh/lb = 46 kWh, which requires a charging rate of 5.3 kW over a 12-h period or 8.0 kW over an 8-h period.

Assuming the electric car to be energized entirely from the household meter, then the average yearly energy requirement for the reference 3150-lb electric car is 0.68 × 10 000 = 6800 kWh. Similarly, the average yearly energy requirement for the optimized 2000-lb electric car is 0.32 × 10 000 = 3200 kWh. For comparison, the average nationwide annual use of electric energy per residential customer in the United States during the year 1970 was 7066 kWh. The forecast for the year 1990 is 19 037 kWh. [12]

These examples show that the requirements are not out of bounds and may be accommodated by careful future planning by the utilities. The added revenue potential created by electric cars would justify the investment by electric companies to provide adequate distribution systems and install special instrumentation for charging the batteries of electric cars and timing the duration and amount of their charging. For example, even at the present time several types of controls are used for timing the power flow to the electric water heater installations, such that the heater element is supplied mostly during the off peak periods. A similar control can be used in charging the batteries so that the overnight charging power will be automatically controlled with time and the peak limited to acceptable levels.

The effect of nighttime charging during off peak periods would yield a better utilization of the available capacity and consequent reduction in the relative cost of producing electricity, due to the reduction in idle time for expensive machinery.

Impact on Nationwide Pollution

The increase in pollution from electric power generation plants caused by widespread use of electric cars is generally proportional to the increase in energy demand caused by electric cars. As shown earlier, the anticipated increase in energy is negligible and consequently, the increase in pollution is negligible.

A detailed comparison of the projected nationwide pollution with and without the use of electric cars was made in [3]. For the extreme case discussed previously leading to the total replacement of heat engines by the year 2000, the comparison indicates the significant advantage of electric cars in reducing future nationwide pollution.

SUMMARY AND CONCLUSIONS

1) The ac energy fed to the battery charger of a reference electric car of 3150-lb curb weight energized by a future high energy-density battery, is 0.68 kWh/mi. This compares with an energy consumption of 2.82 kWh/mi provided by the gasoline in the fuel tank of a baseline conventional heat engine car of equal weight. The average efficiency of the electric car is 42 percent compared to an average efficiency of 12 percent for the heat engine car. The energy consumptions for both cars are based on an identical driving schedule comprising of a mixture of high speed and suburban driving.

The reference electric car is assumed to have air drag and rolling resistances comparable to a conventional car of equal weight and a combined battery charge–discharge efficiency of 72 percent. The assumed efficiency for the electric drive components are achievable with current technology. The motor provides an infinitely variable transmission without gear shifting and powers the rear wheels through a conventional differential. The energy consumptions include heating and air conditioning requirements per mile and are based on a yearly average.

2) The overall energy consumption (heat in coal or other fuel fed into the electric power generating plant) for the reference electric car is 2.13 kWh/mi. This compares with an energy consumption of 2.96 kWh/mi for the baseline heat engine car of equal weight (energy in crude oil fed to refinery). The overall system efficiency of the reference electric car is 13.5 percent compared with an efficiency of 10 percent for the baseline heat engine car.

3) The reference electric car in addition to having an overall energy requirement about 25 percent lower than the heat engine car also allows multifuel operation capability. That is, it can operate from nuclear, fossil, hydroelectric, or any other future clean source of energy used in the central generating plants such as solar or geothermal sources. Widespread use of the electric car would save limited oil resources for other uses.

4) Electricity generated by nuclear power plants appear to be the most feasible solution for satisfying the future demand for energy. Widespread use of electric car is complementary to implementing this solution.

5) The reference electric car, used only to provide an equal basis for comparison with heat engine cars, is not considered a practical electric car. Even with a high energy and power density battery (100 Wh/lb and 100 W/lb) constituting about 25 percent of the car weight, the driving range, would be limited to only 1[illegible] mi at 70 mi/h or 203 mi at 55 mi/h. The analyses indicate that by proper streamlining of the reference car and improvements in the efficiency and materials of its drive line components the overall energy consumption may be reduced to at least [illegible] percent of the energy consumption of the baseline heat engine car of equal weight (3150 lb), and the driving range increased to more than 250 mi.

6) Due to the continuing trend to smaller car size and the need for reducing energy consumption and the impact of electric cars on power generation and distribution systems, it is

TABLE VII

	Estimated Weight (lb)	Percent of Total Car Weight	
Battery	750	23.5	39.5
Motor (ac)	140	4.5	
Controls	140	4.5	
Cables, cooling systems, wiring, and propulsion accessories	65	2.0	
Drive line (includes reduction gears)	155	5.0	
Steering and brakes	190	6.0	
Climate control, radio, gauges and warning devices	50	1.5	
Body, frame, suspension, tires interiors, etc.	1660	53.0	
Total	3150	100	

anticipated that future electric car population would have an average curb weight of 2000 lb or less and will be optimized for minimum energy consumption. The estimated ac energy fed to the battery charger of an optimized 2000 lb car using high energy-density battery and comparable in performance to a conventional car is in the range of 0.30 kWh/mi. This corresponds to an overall energy consumption in coal fed to the electric power generating plant of about 1 kWh/mi which is only half the overall energy consumption of a conventional heat engine car of equal weight provided by crude oil fed to the refineries.

7) Assuming the future availability of practical high energy-density batteries, leading to a gradual growth of electric car population approaching 72 million cars by the year 2000, (40 percent of total passenger car population), the anticipated energy demand would be less than 3 percent of the overall nationwide energy demand for electric energy (assuming optimized electric cars of 2000 lb average weight).

8) The impact of an optimized 2000 lb future electric car energized solely from a residential supply is comparable to or less than the impact of domestic air conditioning or electric space heating units. However, in contrast to heating or air conditioning, the energy for electric cars could be provided overnight during off peak periods. This would have a desirable effect on the economics of power generation and may be encouraged by utilities by providing special metering and low-cost energy during overnight charging.

9) From the limited data available in literature, it can be concluded that the energy consumption ratio of electric to heat engine cars is lower during city and metropolitan driving involving low speeds and frequent stops compared to high speed and [illegible] than those used in this paper as basis for energy comparison. It is hoped that future investigators will provide refined data for representative city and metropolitan routes by actual driving of the two car types on identical routes.

10) Measured data obtained from actual road testing of available limited performance electric cars powered by lead acid batteries show that the average energy requirement per mile supplied by coal fed into the electric power generating plants is only half the average energy requirement per mile for a conventional heat engine car of equal weight supplied by crude oil fed into the refineries. It is noted however, that these cars are still in their experimental states, and their energy consumption may be reduced further in improved future generations.

TABLE VIII

Item	Percent of Total Car Weight	
Engine	16.0	31.0
Transmission	4.5	
Fuel system (includes full tank of gasoline)	4.5	
Exhaust	1.5	
Drive line	4.5	
Steering and brake	6.0	
Climate control, radio, gauges and warning devices	1.5	
Electrical supply and circuitry	1.5	
Body, frame, suspension, tires, interiors, etc.	60.0	
Total	100	

APPENDIX I

WEIGHT DISTRIBUTION FOR AN ELECTRIC CAR USING FUTURE HIGH ENERGY AND POWER DENSITY BATTERY

In order to allow for passenger room and luggage compartment comparable to conventional cars, it is necessary to limit the battery weight to 25 percent of the total car weight. With this weight limitation a high energy and power density battery (100 Wh/lb and 100 W/lb), when available in the future, can provide driving range and performance comparable to conventional cars. Based on the allowable battery weight assumed, the estimated weight of various components for a 3150-lb electric car and the corresponding percent contribution to the total car weight are tabulated in Table VII. For the ease of comparison, it was assumed that the electric motor drives the rear wheels through a conventional differential. In an ideal electric car each wheel can be driven by a separate motor and the conventional drive line could be eliminated.

For the purpose of comparison, the percent weight contribution of various components in a conventional heat engine passenger car to the total car weight is tabulated in Table VIII.

The weight distribution for an electric car is based on an ac motor drive system comprising a 140-lb motor + 140-lb controls = 280 lb. A dc motor drive system is estimated to be 130 lb heavier and increases the overall car weight by 4 percent. The combined efficiency of motor and power conditioner in both the ac and dc motor drive systems are estimated in Appendix II and are approximately equal. Since the energy consumption of a given vehicle is approximately proportional to the weight (see Appendix II and III), the electric car with dc motor drive consumes about 4 percent more energy than a similar electric car with advanced ac motor drive.

The difference is negligible, therefore, the results in this paper are approximately applicable to future electric cars using either ac or dc motor drive systems.

Appendix II

Backup Data for Energy Consumption and Component Efficiency of Electric Cars

Energy Consumption

Due to the lack of high energy-density batteries, all the electric cars available are of limited performance. Several of these cars have been tested and the energy consumption (the ac energy input to the battery charger corresponding to 1 mi of driving) were measured for several operating modes. Actual measurements for two experimental cars are given below. This energy consumption does not include heating or air conditioning requirements.

1) An electric car Mars II of 4650-lb test weight (including 1840 lb of lead acid batteries) built in 1967 by the Electric Fuel Propulsion Company and has a driving range of 60 mi at 60 mi/h (or 120 mi at 30 mi/h). This car was tested by the Cornell Aeronautical Laboratory [13] and [14], and the amount of ac energy fed into the charger for various drive cycles were measured and expressed in kWh/mi as shown.

	Average Speed	Energy Consumption
City driving	22.4	0.60
Urban driving	19.3	0.72
Hilly terrain	33.4	0.65
Average		0.66 kWh/mi

2) An electric car of 2000-lb test weight (including 750 lb of lead acid batteries) built by the McKee Company and having a driving range of about 60 mi at 60 mi/h (or 140 mi at 30 mi/h). The car was tested by ESB Corporation [15], and the amount of ac energy fed into the charger for various driving cycles were measured as shown.

Residential driving cycle (SAE J 227)	0.25–0.28 kWh/mi
Metropolitan driving cycle (SAE J 227)	0.31–0.37 kWh/mi
Average	0.30 kWh/mi

These data indicate that the energy consumption is approximately proportional to the vehicle weight. This relationship, as shown in Appendix III, is also true for conventional cars. On this basis the energy consumption for a 2000-lb and a 3150-lb curb weight limited range electric cars is estimated and shown below to provide a reference for comparison with high performance electric cars of the same size discussed in the paper. Also shown are the corresponding energy requirements in fuel fed into the electric power generating plant, assuming an efficiency of 35 percent for the generating plant and 91 percent for transmission and distribution. In determining the consumptions an extra weight of 250 lb was allowed for passengers.

Curb Weight of Limited Range Electric Car (lb)	AC Energy Fed to Charger (kWh/mi)	Energy in Coal Fed to Electric Power Plant (kWh/mi)
2000	0.33	1.04
3150	0.50	1.58

It is noted that a direct comparison of the energy consumption for the preceding 3150-lb limited range car with the reference electric car of equal weight, discussed in the paper, is not justified due to the differences in the driving cycles used and the high values of auxiliary and comfort energy assumed for the reference car. Also gear shifting was used in the limited range cars while in deriving the energy consumption for the reference car no gear shift was assumed. Allowing for these differences, the preceding measurements can provide a reasonable base line for comparison. It is also noted that the limited range cars are experimental cars using available components and considerable improvement in efficiency of future generations is expected.

Component Efficiency

Backup data for the efficiencies of major components assumed in the paper for the reference electric car follows. The anticipated improvements in these efficiencies for an optimized future electric car is also discussed.

Battery: 1) The assumed charge efficiency is 90 percent, 2) the assumed discharge efficiency is 80 percent, and 3) the combined charge-discharge efficiency is 72 percent

The charge and discharge efficiency of a battery depends on the rate of charge and discharge. A constant cruise speed of 70 mi/h (assuming a 750-lb high energy and power density battery) corresponds to about a 3-h discharge rate. The charge rate will probably be much lower (for example, overnight charging). These efficiency figures are comparable to lead acid battery efficiency achievable in limited range cars presently used.

A high energy and power density battery implies that the battery must possess low internal resistance and consequently high efficiency. Cell measurements at the Argonne National Laboratory for a lithium-sulfur system indicate a combined charge-discharge efficiency higher than 80 percent at a 1-h rate [16]. Similar high efficiency trends have been reported by Dow Chemical Company on the sodium/sulfur system [17]. Based on these data, and considering the lower charge and discharge rate indicated previously for electric cars, it is anticipated that future high energy and power density batteries may have a combined charge and discharge efficiency higher than 80 percent compared to 72 percent efficiency assumed for the reference electric car. To achieve high efficiency in the electric drive systems a high battery voltage of 350 V is assumed.

Motor and Power Conditioner. 1) The assumed efficiency at 70 mi/h cruise speed is 86 percent, 2) the assumed driving cycle efficiency without gear shift is 65 percent, and 3) the assumed driving cycle efficiency with automatic gear shift is 76 percent

DC Motor: One of the drive scheme used in current electric cars is the chopper controlled dc series motor. In this scheme, a choke is normally used in series with the motor armature to reduce harmonic losses in the motor. The losses in chopper components and associated choke reduces the overall system efficiency appreciably. Though the use of a chopper is necessary at low motor speed (below 1/3 rated speed) and light loads, they can be bypassed completely in a separately excited dc motor at high speed cruising and acceleration, where the motor can be directly connected across the battery and the power varied smoothly by field control. The chopper will only be used at lighter loads or lower speeds when needed. In such a scheme, the motor can be optimized for high speed normal cruising where efficiency equal to motor efficiency ranging from 86–90 percent may be achieved (from battery terminal to motor shaft).

For the Federal Driving Cycle, the average motor speed is low and the use of chopper or other means of power conditioning is needed to provide smooth and efficient control. In [20, pp. 47–48] the average efficiency of a dc motor-chopper combination over a driving cycle were calculated, assuming a 65-hp 4650-r/min motor of 325-lb weight and 90-percent efficiency at rated load. The results are summarized as follows.

1) There is a motor efficiency of 75 percent and a chopper efficiency of 90 percent (a combined efficiency of 67.5 percent), assuming a fixed gear ratio between motor and differential.

2) There is a motor efficiency of 83 percent and a chopper efficiency of 92 percent (a combined efficiency of 76 percent), with step gear changes used over the driving cycle.

Also, the effect of regenerative braking over the Federal Driving Cycle was analyzed. The results are summarized as follows.

1) Without gear shifting, regenerative braking reduces the battery energy requirements by 13 percent.

2) With a one-step gear shift, regenerative braking can reduce the battery energy requirements by 17 percent.

AC Motor: To achieve high efficiency in an electric car the motor must have high efficiency during both full-load and part-load operation over a wide speed range. The following is a description of a motor meeting this requirement which was tested in an electric car (Electrovair-I) powered by a silver-zinc battery [18].

"A squirrel cage induction motor of 130-lb weight was operated from an inverter in a controlled slip mode. The motor was installed in a Corvair where the engine was removed and replaced by an electric drive. Acceleration capability of 0–60 mi/h in 16 s was demonstrated by road tests. The motor drive provided an infinitely variable transmission, that is, no gear shifting."

The calculated part-load and full-load efficiency of the motor shown in [19] indicates.

> That for a constant horsepower level of 90 hp maintained over a speed range of 3380–10 000 r/min, the motor efficiency varies from about 92–94 percent
>
> That for a constant horsepower level of 50 hp maintained over a speed range of 5680–13 000 r/min, the efficiency varies from about 92–93 percent.

Based on these data, a cruise efficiency of 92 percent may be used for the motor (assuming a sinusoidal waveshape).

The losses in the inverter are due partly to the switching losses in the power switching devices and mainly to the losses in the auxiliary power components used to shut off the power switching devices. Also, the harmonic components associated with the nonsinusoidal output of the inverter cause degradation in motor efficiency. Combining all these effects (including degradation in motor efficiency due to harmonics), the efficiency of the inverter corresponding to 70 mi/h cruise speed is estimated as 94 percent. The overall motor-inverter efficiency is therefore, 86.5 percent. Some improvement in this efficiency is possible with improved future thyristors of short turn off time and improved low loss shut-off capacitors.

To the best knowledge of the author, no data are available in literature regarding the efficiency of ac motor drives over representative driving cycles. It is the author's opinion that the efficiency would be comparable to those for dc drives.

Central Electric Generating Plants: The assumed efficiency is 35 percent. No significant improvement in this efficiency is anticipated before 1990. Beyond this period the use of fast breader liquid metal reactor with topping cycle (efficiency as high as 42 percent) may increase the nationwide average efficiency above the value shown.

APPENDIX III

BACKUP DATA FOR ENERGY CONSUMPTION AND COMPONENT EFFICIENCY OF CONVENTIONAL HEAT ENGINE CARS

Energy Consumption

There is a lack of consistent data on fuel economy (miles per gallon) over the Federal Driving Cycle and constant cruise speed. The data used as input to this study came from two sources [7] and [8] which were the only set of consistent data available to the author. In [7] the fuel economy over the Federal Driving Cycle is given for a large number of cars covering each of the model years from 1957 to 1973. This reference however, does not cover fuel economy at constant cruise speeds. The constant speed fuel economy data for a large number of pre 1970 cars is given in [8]. Hence the model years 1968 and 1969 were chosen as basis for this study since the fuel economy data for both types of driving modes (driving cycle and constant cruise speed) were covered by the two references.

The fuel economy is normally expressed in miles per gallon. Another convenient way of expressing fuel economy is in terms of gallons consumed per mile per pound. Such an expression as shown next is approximately independent of vehicle weight and gives a true measure of energy conversion efficiency.

Fig. 13, is a plot of fuel consumption versus vehicle weight over the Federal Driving Cycle where the fuel consumption is expressed in gallons per mile per pound. The plot represents the average of measurements on 178 cars of the 1968 and 1969 model years derived from [7].

Similarly Fig. 14 is a plot of fuel consumption versus vehicle weight at constant cruise speeds of 70, 60, 50, 40, and 30 mi/h, where the fuel consumption is again expressed in gallons per mile per pound. Each plot represents the average of measurements on a large number of cars of the 1968 and 1969 model years derived from [8]. For example, the 70 mi/h plot is the average of measured fuel consumption on 23 cars each represented by a point shown in the vicinity of the curve. It is noted that in determining each of these points, 250 lb was added to the corresponding vehicle curb weight given in the reference to allow for passenger and extra weights.

From an examination of Figs. 13 and 14 it can be seen that the specific fuel consumption, expressed as gallons per mile per pound, varies only slightly with vehicle weight and is approxi-

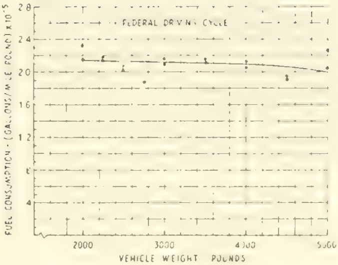

Fig. 13. Fuel consumption of conventional heat engine cars over the Federal Driving Cycles (1968–1969 model years).

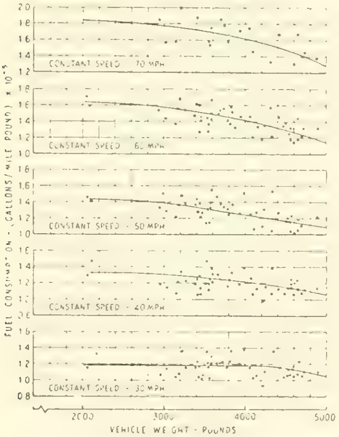

Fig. 14. Fuel consumption of conventional heat engine cars at constant cruise speed (1968–1969 model years).

mately constant for a wide variation in weight. This is particularly true at low speeds and over the Federal Driving Cycle. The variations are relatively higher at higher speeds due primarily to the nonlinear variations in aerodynamic resistance with weight. From these results, average fuel consumption for three cars of 2000 lb, 3150 lb, and 4300 lb curb weight were calculated and shown in Table IX, where an additional weight of 250 lb was added to each car to allow for passenger and accompanying loads.

The fuel consumption may be converted to energy consumed (Btu or kWh) by using the following expressions.

energy in Btu/mi = 120 000 × (gallons of gasoline consumed per miles traveled),

energy in kWh/mi = 35.1 × (gallons of gasoline consumed per miles traveled.

These conversions factors were calculated by assuming an energy content of 120 000 Btu per gallon of gasoline, 1 kWh = 3413 Btu

The calculated energy consumption in kWh/mi for a 2000 lb, 3150 lb, and 4300 lb conventional 1968–1969 model year cars are shown in Table X. Also shown is the projected energy consumption for corresponding cars meeting the 1975–1976 emission standards derived by assuming a 10-percent increase in fuel consumption. These data are used as basis for comparison with the same size electric cars discussed in this paper.

Component Efficiency

The efficiency of various components of the power train of a conventional heat engine car of 4300-lb weight were estimated at a constant cruise speed of 70 mi/h [21] and are given as follows.

Component	Efficiency at 70 mi/h
Automatic transmission	87 percent
Torque converter	96 percent
Differential and axle	96 percent

TABLE IX

Fuel Consumption (gallon per mile per pound) × 10^{-5}			Fuel Economy (miles per gallon)		
Curb Weight	70 mi/h	Federal Cycle	70 mi/h	Federal Cycle	Average
2000 lb	1.82	2.13	24.4	20.9	22.6
3150 lb	1.72	2.10	17.1	14.0	15.5
4300 lb	1.47	2.07	14.9	10.6	12.7

TABLE X

Energy Consumption for 1968–1969 Cars (kWh/mi)				Projected Energy Consumption for Cars Meeting 1975–1976 Emission Standards (kWh/mi)		
Curb Weight	70 mi/h	Federal Cycle	Average	70 mi/h	Federal Cycle	Average
2000	1.44	1.68	1.56	1.57	1.85	1.71
3150	2.06	2.51	2.28	2.27	2.77	2.52
4300	2.35	3.31	2.83	2.59	3.64	3.11

TABLE XI

	Gasoline Plant	Fuel Oil Plant
Energy content of feed, Btu/barrel	6 000 000	6 000 000
Product energy contents, Btu/barrel of feed		
Gasoline	4 400 000	1 920 000
Fuel Oil	—	3 330 000
Coke	260,000	260 000
Less plant power consumption, Btu/barrel of feed	200,000	150 000
Overall thermal efficiency, percent	75	89

Efficiency of Refineries

There is a certain amount of energy loss involved in refining crude oil to gasoline and transporting and distributing the gasoline for use in passenger cars. A thermal efficiency can thus be assumed for refining and handling gasoline. Accurate efficiency data, however, are not available due to the complexity of the processes involved and the proprietary nature of these data.

In a preliminary investigation conducted in [25] the thermal efficiency of refinery operation was estimated and is shown in Table XI based on 30.7 the American Petroleum Institute (API) low sulfur crude.

Note that the data in Table XI show an efficiency of about 89 percent for a refinery producing gasoline plus fuel oils compared to an efficiency of about 75 percent for a gasoline plant. It is indicated in [25], that the derivation of the data are based on approximate and simplified assumptions, and therefore the conclusions based on these data should be made cautiously. It is further indicated that the nature of refining operation is changing rapidly which will effect the preceding results.

According to other energy input/output analysis [26] and [27], the production of 1 Btu of refined petroleum requires a total input of the petroleum refinery sector of 1.15 Btu, which corresponds to an efficiency of 87 percent.

It is noted that in a refinery producing gasoline and other products, a relatively large portion of the process energy is attributable to refining the gasoline and therefore, the efficiency attributable to refining the gasoline is much lower than the overall refinery efficiency. Also in addition to refining gasoline, other losses occur in transporting the gasoline to gas station and distributing the gasoline. These losses were estimated at 2 percent total.

Based on the limited data an efficiency of 85 percent is assumed for refining and distributing gasoline. This efficiency appears to be on the high side, and it is hoped that further investigation will provide more thorough efficiency analysis.

APPENDIX IV

COMPARISON OF THE ENERGY REQUIREMENTS FOR LIMITED PERFORMANCE ELECTRIC CARS WITH CONVENTIONAL HEAT ENGINE CARS

From the results of Appendixes II and III, the average energy requirement per mile of driving for a 2000-lb limited performance electric car powered by lead acid batteries are shown together with the energy requirement for a conventional heat engine powered car of equal weight.

2000-lb Limited Performance Electric Car:

ac energy fed to the battery charger	0.33 kWh/mi.
heat energy in coal fed to generating plant	1.04 kWh/mi.

2000-lb Conventional Heat Engine Car:

heat energy in gasoline of fuel tank	1.71 kWh/mi.
heat energy in crude oil fed to refineries	2.00 kWh/mi.

It can thus be concluded that the available electric cars consume only half the energy requirement of a conventional heat engine car of equal weight. It is noted however, that the available electric cars are still in their experimental states, and their energy consumption may be reduced further in future improved generations.

ACKNOWLEDGMENT

The author wishes to express his gratitude and indebtedness to J. J. Brogan, Director of the Advanced Automotive Power Systems Division of the Environmental Protection Agency for his contributions and encouragement which made this paper possible. He wishes also to thank S. B. Kramer for his valuable comments and review of the manuscript.

REFERENCES

[1] J. T. Salihi, "Two for the road," *IEEE Spectrum*, vol. 9, pp. 43–47, July 1972.

[2] E. Cook, "The flow of energy in an industrial society," *Sci. Amer.*, pp. 135–144, Sept. 1971.

[3] [illegible], "Electric cars: facts and fancy," *IEEE Spectrum*, vol. 9, pp. 44–48, June 1972.

[4] *[illegible]*, vol. [illegible], no. 2, [illegible] pt. II, Oct. 11, 1970.

[5] "Vehicle design goals," Revision B, Advanced Automotive Power Systems Development Div., Office of Air Programs, Environmental Protection Agency, Feb. 11, 1971.

[6] A. D. Little, "Prospects for electric vehicles—a study of low pollution potential vehicles," prepared under Contract PR 86-67-108 to National Air Pollution Control Administration, Oct. 1969.

[7] "Fuel economy and emission control," Office of Air and Water Programs, Environmental Protection Agency, Tech. Rep., Nov. 1972.

[8] Consumer Reports, pp. 33, 93, 153, 329, 359, and 549, 1968; pp. 29, [illegible], 189, and 528, 1969.

[9] D. M. Tenniswood *et al.*, "Minimum road load for electric cars," SAE Paper 670177.

[10] "Abatement of sulfur oxide emission from stationary combustion sources," Div. Eng., National Research Council, Washington, D.C., 1970.

[11] [illegible], "Annual growth rate on downward trend," *Elec. World*, pp. 30–34, July 6, 1970.

[12] "22 annual electric forecast," *Elec. World*, Sept. 15, 1971.

[13] "Technical report on Mars II electric automobile," Cornell Aeronaut. Lab., Cal. no. JV-2623-K-1.

[14] "The Mars II electric car," SAE Paper 680428, Detroit, Mich., May 1968.

[15] R. S. McKee *et al.*, "Sundancer—a test bed electric vehicle," SAE Paper 720188, Automotive Engineering Congress, Detroit, Mich., Jan. 1972.

[16] E. J. Cairns, Chem. Eng. Div., Argonne National Lab., private communication, Aug. 1972.

[17] "Development of the hollow fiber sodium sulfur battery," Dow Chemical Co., Walnut Creek, Calif., Third Quarterly Rep., Apr.–July, 1972, prepared under U.S. Government Contract NOO 298-72-C.

[18] J. T. Salihi, P. D. Agarwal, and G. J. Spix, "Induction motor control scheme for battery powered electric car (GM Electrovair II)," *IEEE Trans. Ind. Gen. Appl.*, vol. IGA-3, pp. 463–469, Sept./Oct. 1967.

[19] P. D. Agarwal, "The GM high-performance induction motor drive system," *IEEE Trans. Power App. Syst.*, vol. PAS-88, pp. 86–93, Feb. 1969.

[20] G. J. Gelb *et al.*, "Cost and emission studies of a heat engine/battery hybrid family car," TRW Systems Group, Apr. 1972. Final

report prepared for the Advanced Automotive Power Systems Development Div., Environmental Protection Agency, under Contract 68-04-0058. (National Technical Information Service Publication PB-215-280.)

[21] "Hybrid propulsion systems transmission evaluation, phase I," Sundstrand Aviation Rep. AER 640, Oct. 1971, prepared for the Advanced Automotive Power Systems Div., Environmental Protection Agency, under Contract 68-04-0034 (National Technical Information Service Publication PB-210-057.)

[22] R. T. Kent, *Mechanical Engineers Hand Book*, 11 ed. New York: Wiley, pp. 14-67.

[23] *Petroleum Facts and Figures*, 1967 ed., American Petroleum Inst., pp. 87 and 246.

[24] "The comparative environmental impact in 1980 of gasoline-powered motor vehicles versus electric-powered motor vehicles," Gordian Ass., Oct. 1971, Report prepared for the Electric Vehicle Council.

[25] A. Sun, Garrett Research and Development Co., Inc., Subsidiary of Occidental Petroleum Corp., private communication, Mar. 21, 1972.

[26] E. Hirst, "Energy consumption for transportation in the U.S.," Oak Ridge National Lab., Tech. Rep. ORNL-NSF-EP-15, Mar. 1972.

[27] W. A. Reardon, "An input-output analysis of energy use changes from 1947-1958 and 1958-1963," Battelle North West Labs., Richland, Wash., Tech. Rep., 1971.

HALFTONES

57a

Jalal T. Salihi (S'53-M'58-SM'70) was born in Sulaymania, Iraq. He received the B.S. degree from the University of Leeds, Leeds, England, in 1948 and the M.S. and Ph.D. degrees in electrical engineering from the University of California, Berkeley, in 1954 and 1957, respectively.

He joined the Advanced Automotive Power Systems Development Division of the Environmental Protection Agency (EPA), Ann Arbor, Mich., in 1971, as Chief of the Hybrid and Electrical Systems Branch heading the development programs for batteries and propulsion systems for electric and hybrid cars. He is now Assistant to the Director of the division. Prior to joining EPA, he was with the General Motors Research Laboratories for seven years as a Supervisory Research Engineer where he directed research in brushless electric propulsion schemes and overall control systems for electric cars, off-highway vehicles, and industrial applications. From 1959 to 1963 he was a Faculty Member and Acting Chairman of the Electrical Engineering Department of the University of Baghdad, Iraq. From 1957 to 1959 he was a Staff and Project Engineer with Lenkurt Electric Company, San Carlos, Calif., where he was engaged in research and development of signaling and communication systems. He holds sixteen United States Patents and is the author of several papers.

Dr. Salihi is a member of the Static Power Converter Committee of the IEEE Industry Applications Society, the Electric Vehicle Technical Committee of the Society of Automotive Engineers, and the Steering Committee of the United States Interagency Advanced Power Group.

Mr. CAMPBELL. We feel that the inclusion of hybrids and other alternatives to the straight electric vehicle could dilute the effort and delay the development of what we feel is inevitable, and that is the total electric vehicle, and for those reasons we would suggest that those alternatives, shall I say, be "soft pedaled."

The hybrid, as Dr. Roan said Tuesday, is an interim solution, but it does use gasoline, and any interim solutions other than development of electric vehicles would perhaps take some of the fire away from what we need to do on the electrics.

At least two of the people who have spoken to the committee this week have emphasized the more immediate feasibility of the closed-loop urban delivery vehicle, and I would like to say that the Council also recognizes this and has funded a program over the last 2 or 3 years to develop a small urban delivery van, which we have put in the hands—107 of them—of 61 utility companies, and we're collecting data on their operation, so far over 86,000 miles of operation.

There is one thing that Dr. Thornton mentioned at the outset that I think after 3 days we all agree, that there are many facts and figures thrown around which conflict with each other, which are sometimes confusing, and what I think they indicate is the need for standards of performance and even standards of nomenclature in describing what's done in testing, and I think that I would recommend that the committee consider that if this bill were to go forward any vehicle that was a part of it would be preceded by a setting up of performance standards and a uniform way of describing things.

I think we've seen vehicles out here Tuesday which looked the same, have the same number of batteries, and one person will say, "It will go 100 miles," and the other one says, "It will go 40 miles," and that's a matter of easily straightening out the wording.

I would like to offer the services of the Electric Vehicle Council, if so desired, to set up an industry committee to attempt to establish uniform wording and standards of performance.

I would like to add, in that connection—and I think that Mr. Brown mentioned this a few minutes ago—that using money, such as a half a cent, or a cent, or 3 cents, or whatever, to describe the aspects of electric vehicles immediately runs into the problem of the basis on which the money was figured out. Even Dr. Thornton's reference to electric rates doesn't take into consideration the fact that electric rates vary all over the country. They won't react the same way in the future in all parts of the country, and gasoline, taking notice of what Dr. Kane said the other day, will have more taxes on it, rather than no taxes, and that those only get us into a trap. It would be better to describe it on the basis of something like kilowatt hours or Btu's, and equate things to the same terms, and not be confused by the fact that somebody say it will cost 1.9 cents a mile and somebody says it will cost 10.

I do feel, though, that all the discussion of high life cycle cost of batteries seemed to revolve around why is there such a variation, and nobody mentioned the fact that all the figures seemed too high. Lead-acid batteries, regardless of their suitability for the distant future of electric vehicles, are a very well developed product right now, and the facts and figures are well obtainable.

One thing that Dr. Kane emphasized, and one thing that I think is way off base, and that is that there is not a high cost per mile in using them. But that's, I might say, rather that because I dont' think we should use pennies to describe it.

I don't want to add any more except to say that all our discussion of costs, relative performance, and whatever, are relatively unimportant if we are going to run out of petroleum, and it was called to my attention there is a sign on a building downtown which changes every day and says something like, "Today is 3,420 days until we run out of our domestic supply of petroleum." I don't know about their numbers, but it gets across the point. That is, I think, the big thing we have to aim toward.

Thank you very much.

Mr. McCormack. Thank you very much, Mr. Campbell.

I have just a couple quick questions I would like to ask you.

When we conceived this bill we conceived the idea of half the vehicles that would be manufactured using just American bodies and chassis, and half from the ground up.

Does this concept make sense to you, or would you recommend they all be made from the ground up?

Mr. Campbell. I think it makes sense to start off in the first year with existing chassis, because a lot of information can be obtained from operating those vehicles, even though they're not the best vehicles that could be produced, and also getting the public aware will get started sooner and will also make it possible for some small manufacturers, or even experimenters, who don't have the capability of building chassis and bodies from the ground up, to demonstrate whatever special technique they have for propulsion of the vehicle.

Mr. McCormack. Following that, then, let us make some assumptions, and be guided by the admonition of Congressman Hechler here about delays. Let us assume for a moment, rather optimistically, I suppose, that we could get this law enacted and funded by the end of this calendar year. Now, that is pretty optimistic. And let us assume that ERDA would take 6 months to get contracts let for purchases and establish performance criteria. How long do you think it would take in months, 6, 12, 18, 24 months, to have manufactured and delivered 5,000 vehicles, using existing automobile bodies and chassis, and buying from maybe 10 to 20 manufacturers? I am pulling numbers just out of the air.

I am curious to know when, how long do you think it would take? Would it take a year after orders were let to do this, or a year and a half, or what?

Mr. Campbell. I think it could be done in a year. I doubt if it can be done in less than a year.

Mr. McCormack. This would mean that some vendors might be producing 500 vehicles. Do you think that is too ambitious?

Mr. Campbell. Some have that capability.

Mr. McCormack. I see.

Do you see a significant difference in cost to manufacture in the immediate future between vehicles that are built using existing bodies and chassis on the one hand, or building them from the ground up on the other? Is there a significant difference, or would it be in the same ball park, depending upon other factors?

Mr. CAMPBELL. I think it would be in the same ball park, because it's the electric drive, transmission and storage of energy that is the more expensive part, or the harder part, to mass produce, I would say.

Mr. MCCORMACK. All right. One quick question.

You suggested that we deemphasize hybrids and put the primary emphasis on battery operated vehicles.

Where do you put flywheels, in what category? Would you put them in with electric vehicles, or in with hybrids, or in a category by themselves? And how would you compare flywheel vehicles in the event someone comes up with a flywheel that would be viable in generating an amount of energy, to the battery?

Mr. CAMPBELL. I would put them much farther out into the future than either straight electrics or hybrids. There is work being done on them, and I don't think anybody anticipates a useable pilot any sooner than we anticipate a sodium-sulfur battery, if that soon.

Mr. MCCORMACK. Thank you.

Mr. Hechler.

Mr. HECHLER. Mr. Campbell, I notice on the bottom of page 9 of your prepared testimony, which you did not orally deliver, that there are a number of State laws, such as one State has a $15 extra charge because electric vehicles don't pay gasoline taxes, and other States have laws that require certain size gasoline tanks, and things like that.

Even though you said that you didn't have documentation, I think it would be real helpful for the record if you could supply, or if you have now, the names of any of these States that have this inhibiting legislation.

The second part of my question: Is there any inhibiting Federal legislation on the books that might similarly slow down our efforts in this respect?

Mr. CAMPBELL. As far as the Federal legislation is concerned, there are some probable safety provisions, and possibly emission provisions, which would have an inhibiting effect. On the air quality, there is no way that an electric vehicle can get, shall we say, a clean bill of health. They're not testable. I think at times the EPA has said that it was an inherently low pollution vehicle, but something extra would be necessary in order to put them into an appropriate category.

As far as safety is concerned, I think that was mentioned earlier this week, that there are some things that have perhaps up to now been set aside because the number of vehicles produced is very small. If the number got larger it might become significant.

There are some things, such as the impact absorbant bumpers that I could visualize as adding 50 percent more weight to some of these tiny cars that are here, which could never develop as much energy on an impact as the bumpers were designed to take.

Mr. HECHLER. Thank you.

Thank you, Mr. Chairman.

Mr. MCCORMACK. Thank you, Mr. Hechler.

There being no objection, the committee will meet at 2 o'clock this afternoon to continue the hearings. We've worked out with the witnesses who will be testifying. If we have time, we will hear Dr. Beaumont, of Sebring, at the end of this session before we adjourn this morning, because he has a movie and I presume the witnesses and the guests here would like to see it, and then we'll take Mr. Aronson and Mr. Borello this afternoon at 2 o'clock.

Mr. Campbell, I don't want to cut you off, or cut anybody else off, but unless we have other questions, I guess we'll just thank you very much for your testimony, and look forward to continuing working with you in the future.

Mr. CAMPBELL. Thank you very much.

Mr. MCCORMACK. We'll have a continuing dialog as we go along, while writing the bill, and afterward too.

Mr. CAMPBELL. Thank you, sir. We'll be happy to be allowed to do that.

Mr. MCCORMACK. Thank you, gentlemen.

The next witness is Mr. Robert Beaumont, president of Sebring-Vanguard, Inc., of Sebring, Fla.

Mr. Beaumont, welcome.

STATEMENT OF ROBERT G. BEAUMONT, PRESIDENT, SEBRING-VANGUARD, INC.

Mr. BEAUMONT. Thank you.

Mr. MCCORMACK. We apologize to you and to all of the others for the confusion in the schedule. You can see what's happened here.

Mr. BEAUMONT. Is that anything unusual for Congress, Mr. McCormack?

Mr. MCCORMACK. No; it is not unusual at all. We feel very fortunate we have been able to proceed with the degree of order that we have.

Mr. BEAUMONT. I don't know how much time I have, and I'm really loath to read a prepared statement, and I won't.

Mr. MCCORMACK. We will insert it in the record as you have submitted it, if there is no objection, and you may proceed as you wish.

Mr. BEAUMONT. Would you say the chances are fairly good that most of you people will have read this prepared statement, that you actually will have read it, each one?

Mr. MCCORMACK. You are very optimistic, Mr. Beaumont.

Mr. BEAUMONT. I certainly hope so.

Mr. THORNTON. I have read it.

Mr. MCCORMACK. Mr. Thornton has read it and that's one out of three. That is pretty good.

Mr. BEAUMONT. Basically, rather than go into a long dissertation, that paper will stand for itself.

[The complete prepared statement of Mr. Beaumont follows:]

TESTIMONY
OF
ROBERT G. BEAUMONT, PRESIDENT
SEBRING-VANGUARD, INC.

BEFORE THE SUBCOMMITTEE
ON
ENERGY RESEARCH, DEVELOPMENT, AND DEMONSTRATION
ON THE
ELECTRIC VEHICLE RESEARCH, DEVELOPMENT, AND DEMONSTRATION
ACT OF 1975 (H.R. 5470)

JUNE 5, 1975

REPRESENTATIVE MIKE McCORMACK
SUBCOMMITTEE CHAIRMAN

AN APPROACH FOR USE OF FEDERAL FUNDS TO PROMOTE ELECTRIC TRANSPORTATION

I am Robert G. Beaumont, President and Founder of Sebring-Vanguard, Inc., P. O. Box 1963, Sebring, Florida 33870. We are a corporation engaged in the manufacturing and marketing of lightweight electric passenger vehicles. We believe ours is the first serious attempt to produce marketable electric vehicles on a mass-production basis in history.

Our Company has sold and delivered over two million dollars worth of electric vehicles since we began production in May of 1974. Our progress in the marketplace certainly indicates that technology for viable electric vehicles exists today. Based on our Company's experience, and my twenty-year personal involvement in all phases of automotive marketing, I would like to make the following recommendations for the implementation of the timely goals set out in H.R. 5470 towards which we wholeheartedly endorse.

A five-part program should be considered. It would encompass:

1. A 10,000 electric vehicle purchase demonstration program.

2. A quasi-governmental entity to administer the above program.

3. A design, prototyping and educational program.

4. Integral componentry and battery research and development program.

5. Miscellaneous studies indigenous to 1, 2, 3, and 4.

Before detailing the program, let me attempt to finally dispel a myth. You have all heard how electric vehicles cannot occupy an important position in personal transportation because no battery yet exists to supply the needed energy. This is an extreme fallacy. The most economical, abundant source of energy for motor powered personal transportation available today is the lead-acid battery.

There are five basic categories of electric vehicles currently available. They are:

1. Two-passenger urban vehicles
2. Four-passenger internal combustion engine conversions
3. Mini-trucks and vans
4. Larger trucks and vans
5. Buses

The Government should fund the purchase of a number of vehicles in each category. These vehicle specifications should be objective and be based on the performance capabilities of the manufacturers who participate in the program, subject of course to the basic limits of the energy source used. The following five-part schedule should provide the incentive for many companies to enter into competition for a contract in the category in which they are capable.

PART ONE

1.	5,000	Two-passenger urban vehicles at $3,000	$15,000,000.00
2.	2,500	Four-passenger ICE conversions at $7,500	18,750,000.00
3.	1,000	Mini-trucks and vans at $7,500	7,500,000.00
4.	1,000	Larger trucks and vans at $10,000	10,000,000.00
5.	500	20 to 30-passenger buses at $30,000	15,000,000.00
6.		Spare parts needed for 3-year period	2,000,000.00
COST OF PART ONE			$68,250,000.00

PART TWO

Despite the many Federal agencies in existence, no single one would be in a position to properly administer all ramifications involved in the distribution and servicing of these various and unique motor vehicles. I recommend that a non-profit business-orientated administrative entity be authorized and funded through ERDA. In addition to handling the ultimate distribution and servicing of the vehicles, this entity (outside of the Federal Government) would: create realistic specifications, receive and disburse the vehicles, test for compliance to specifications, arrange the rental, lease and/or sale of the vehicles and provide all maintenance support and any other functions necessary for the success of the program.

It is my understanding that the spirit of this Act is to stimulate manufacturing of electric vehicles. The other end of the demonstration program is to provide widespread use of these vehicles for acceptance and ultimate purchase. The policies, practices, and procedures of the Federal Government have tended to be exclusionary rather than inclusionary; they tend to favor the sophisticated corporations rather than unsophisticated small businesses; they tend to reward the low bidder rather than the innovator with a meritorious idea. Conformance to Federal purchasing procedures would confront the small entrepreneur and innovator with an unsupportable amount of paper work. With limited manpower available, these organizations, whose principal function is to design and manufacture vehicles, would be forced to divert from their primary jobs to administration of the Government contracts. This is why I suggest that the success of the demonstration part of this Act can be best accomplished by administration outside of the Federal establishment. In essence, this administration would handle the vital and necessary functions which auto dealers now provide for their manufacturer.

The ultimate goal of the administrator of Part Two would be to return to the Government the $68,250,000 expended under Part One. This would result from income when the vehicles are ultimately purchased by either private consumers or Federal, State and local agencies that may buy an EV in lieu of a conventional vehicle.

1. Salaries to cover an approximate staff of 100 for three years	$ 4,500,000.00
2. Advertising and promotional materials	500,000.00
3. Reserve for anticipated service and warranty policy adjustment	1,000,000.00
4. Transportation costs from factory to administration and ultimate destination	1,000,000.00
5. Miscellaneous expenses of the administration including leaseholds	750,000.00
COST OF PART TWO	$ 7,750,000.00

PART THREE

A. Award a design competition contract to ten separate entities which could be comprised of industry and/or universities. Each contract would be worth a million dollars for the purpose of designing and producing prototype electric vehicles.

A precedent for this type project was recently set when DOT awarded the AMF Company a contract for one steam taxi. However, each million dollar contract in this program would require all R & D, tooling and blueprinting necessary for annual production of at least 10,000 vehicles. Service and Parts Manuals for after-market care would also be included. If the entity is not in the position to manufacture the vehicle it creates, then it may offer the knowledge gained to a company willing to produce.

COST	$10,000,000.00

B. Award a contract for two million dollars to create public awareness through the various media. This would acquaint the public with the sociological benefits inherent in electric drive such as quietness, no pollution, and energy conservation.

COST	2,000,000.00

C. Create a program of on-the-job training for mechanics and other service people. This would permit dealers and agencies involved in the sale and service of electric vehicles produced under the program to become rapidly informed about service characteristics of EV's. The selling dealer would be more inclined to send service people to pre-selected areas if his expenses were augmented by such funds.

COST	2,000,000.00
COST OF PART THREE	$14,000,000.00

PART FOUR

Integral componentry is as vital a part of the entire electric vehicle program as Part One. As an inducement for industry to provide their engineering talent to develop such componentry, the following amounts could be prudently expended:

A. Electric motor research	$ 2,000,000.00
B. Control systems for EV's	2,000,000.00
C. Battery recharge systems	2,000,000.00
D. Efficient drive trains	2,000,000.00
E. Chassis specifically for EV's	2,000,000.00
F. Lightweight body materials	2,000,000.00
G. R & D on improving existing batteries and new batteries that could be powering EV's within three years.	14,500,000.00
COST OF PART FOUR	$26,500,000.00

PART FIVE

Certain studies will have to be made to correlate, codify and prove out all phases of the first four parts of the program. A partial listing of reports that would provide usable information could be as follows:

1.	A study of what the rest of the world is doing to promote and develop an electric vehicle industry including a market survey taken among thousands of Americans in different geographical locations as to what consumer preference in electric vehicles would be, including price, style and performance characteristics.	$ 500,000.00
2.	Ramifications to the Federal Government, states and municipalities in connection with fuel taxation, licensing fees and the effect on geographical areas with 20 million electric vehicles in use, including total cost benefits to consumers in reduced depreciation, maintenance, initial cost, fuel cost and insurance as well as the environmental impact of a two-decade changeover to electric vehicles including pollution levels, fuel conservation, congestion and noise abatement.	1,000,000.00
3.	Offer 10 colleges and universities $100,000 contracts for a study of what type electric vehicle should be constructed, how they would be used; and in detail, how their engineering department would proceed to build one.	1,000,000.00
4.	A study of jobs lost and gained as a result of a two-decade changeover from gasoline to electrics including effect on current businesses totally involved in support of ICE auto business and a study to determine the effect of this changeover on the Nation's utility companies including KW capacity, additional capital equity, equipment and personnel need and a consensus from these companies as to problems or ramifications involved in the electric vehicle taking the place of ICE's.	750,000.00

5. A summary of all the above programs including the strength and weaknesses and the compiling of the most salient points in each one.	250,000.00
COST OF PART FIVE	$ 3,500,000.00

PROGRAM SUMMARY

PART ONE	10,000 Vehicle Purchase Program	$68,250,000.00
PART TWO	Three Year Life of Administrative Entity	7,750,000.00
PART THREE	Design, Prototyping and Educational Program	14,000,000.00
PART FOUR	Integral Componentry Plus Battery Research	26,500,000.00
PART FIVE	Miscellaneous Studies	3,500,000.00
TOTAL EXPENDITURES		$120,000,000.00

The $120,000,000 cost would produce results worth far more than the expenditure. Thousands of our best engineering minds would begin working and bidding to get involved in the contracts. Our colleges and universities would jump at the chance to be involved in such an exciting project. The awareness of our Government taking the lead in supporting future technology towards non-petroleum drive would filter through all phases of our social and economic system.

Foreign countries would be greatly stimulated to begin a more active program on electric vehicles and would see the handwriting on the wall. They would not wish to fall behind in automotive technology which is the backbone of so many overseas economies. Here and abroad, a total awareness of battery power as the ultimate energy source for transportation would occur.

In summary, all my adult life in the automobile business, coupled with eight years of electric vehicle experience, leaves me to conclude that the world is eagerly awaiting a new form of personal transportation. If the world can be transformed in a few short years to computer programming of all facets of business, it would seem logical that it shouldn't be difficult to teach the mass market to drive electrically. This market is simply awaiting a product. I congratulate the Committee on taking the initiative to hasten the end of our dependency on petroleum.

Sebring-Vanguard, Inc.
6/5/75

NOTABLE AND QUOTABLE

Roy Cole, Manassas, Virginia
"...a vehicle that will satisfy the needs of a large part of our (driving)..."

George Love, Hendersonville, North Carolina
"I have driven 695 miles and used 210 KWH to recharge the batteries...this is 3/4¢ per mile for fuel..."

Atwater Kent, West Palm Beach, Florida
"...very useful and convenient for the short runs involved...it is easy to park and takes up very little space..."

Frank Haines, Rockville, Maryland
"It saves us money and our country gasoline..."

Ralph Helsel, Wichita, Kansas
"...am finding that it is doing all that I expected it to do...if we had about 10 million of these in operation, we wouldn't have to be importing oil!"

Robert S. Daughaday, Bradenton Beach, Florida
"A truly practical city car..."

Casimir Bobulski, Granby, Massachusetts
'My yellow electric car performs very well..."

Colonel C. A. Des Champs, San Rafael, California
"I am very satisfied with my CitiCar..."

Mrs. Corwin S. Rife, Kalamazoo, Michigan
"That little CitiCar is just great..."

Stephen Keller, Detroit, Michigan
"I just love it...it has my unqualified approval..."

W. G. Skinker, Springfield, Illinois
'My whole family has been enjoying the Vanguard..."

W. B. Woodson, Matthews, North Carolina
"I am delighted with the performance for short trips..."

John Belenger, Cohoes, New York
"I am getting very good service from my CitiCar..."

Sherwood Thomas, (Touhy Pharmacy), Chicago, Illinois
"...we're having good results with it..."

Andrew Larkin, Jupiter, Florida
"....motorized cigar box..."

Martin Metras, Woodstock, Illinois
"Thank you, Vanguard...for CitiCar..."

SEBRING VANGUARD, INC.

NOTABLE AND QUOTABLE

Claude Pepper, Member of Congress, 14th District, Florida, House of Representatives
"...electric vehicles might well be the answer..."

Bill Simmons, Philadelphia Inquirer, Philadelphia, Pennsylvania
"It is basic transportation in the truest sense of the word..."

Houston Post, Houston, Texas
"...CitiCar, the sensational new all electric car...cost of the car is extremely low...a most amazing car..."

Mark Weintz, Star-Advocate, Titusville, Florida
"Angular, squatty, and so ugly it's attractive..."

Greg Hinz, Uptown News, Chicago, Illinois
"...in this era of oil embargoes, the ...electric car is a lot cheaper to operate than the ordinary gas-guzzler..."

Judy Doyle, Sentinel Star, Winter Park, Florida
"The man...zoomed off silently. Without a rumble, a backfire, or a belch of exhaust in the latest thing in economical, pollution-free driving - the electric CitiCar..."

Dan Miller, Chicago Daily News, Chicago, Illinois
"...the CitiCar can thread its way through small openings, park on a dime, and give 8 cents change..."

Olivia Barton, The Birmingham News, Birmingham, Alabama
"Heads turned, mouths dropped and motorists slowed down..."

John Dillin, Christian Science Monitor Service
"...would make an ideal second car for millions of energy short Americans..."

Roger Alan Jones, Sun Chronicle, North Attleboro, Massachusetts
"General Motors said...it'll be five years before we have an electric car... they probably don't know about some creative energy in Florida...it's called the CitiCar..."

Mark D. Marquette, The Republican-Courier, Findlay, Ohio
"...what it lacks in looks and comfort is made up in the pocketbook..."

The Ledger, Lakeland, Florida
"...electric car gets "juiced up" before buzzing around the city on official errands...Lake Wales officials say they are happy with it..."

Peter Bonete, The Bermuda Mid-Ocean News, Bermuda
"...the Utopian vehicle is here...you certainly can't hear the thing moving..."

Harold T. Smith and Dale Betwee, Kalamazoo Gazette, Kalamazoo, Michigan
"...gas stations are the last thing to worry about..."

Susan Baskette, Dallas Shorthorn, Dallas, Texas
"...this car gives the public an alternative..."

SEBRING VANGUARD, INC

Q. How fast does the CitiCar by Sebring-Vanguard go?
A. The current version, CitiCar/SV-48 cruises at up to 38 miles per hour.

Q. Can the CitiCar be licensed for on-the-road use?
A. The CitiCar complies with most Federal Motor Vehicle Standards applicable to that vehicle. Therefore, it should be licensable in all states.

Q. What is the CitiCar designed for?
A. The CitiCar is designed for low speed, short distance driving by housewives, commuters, students, retired persons, etc. Because it has been constructed on a truck chasis, the CitiCar is also ideal for such off-road uses as security patrol, in-plant transportation, etc. The CitiCar has been sold as a messenger and delivery vehicle and is useful for city meter maids and utility companies.

Q. How far will the CitiCar go before recharging?
A. The range is up to 50 miles, depending on temperature, terrain, and traffic conditions. Thirty-five to forty miles is a typical range in city driving conditions. Fortunately, the CitiCar does not use energy when stopped at a light or coasting to a stop.

Q. Will the CitiCar fulfill my driving needs?
A. Chances are it will. The average urban and suburban automobile in the United States is driven only 22.6 miles per day. This makes the CitiCar a very practical second or third car for many families.

Q. How does the top speed hold up as the CitiCar is driven during the day?
A. A top speed of 35-38 miles per hour should be attainable during all but the last few miles of the charge.

Q. How will the CitiCar handle in snow?
A. Exceptionally well; its low center of gravity plus the rear-mounted motor and transaxle provide excellent traction.

Q. What effect do the lights and wiper have on the range of the CitiCar?
A. Owners experience has shown that there is a decrease of approximately 10% in the CitiCar's range during night operation.

Q. Can the CitiCar be towed?
A. Only for short distances at low speed. We recommend using a trailer when taking the CitiCar on vacation.

Q. How will the CitiCar handle on hills?
A. Very well. Avoid climbing long steep hills as it may cause the CitiCar's motor to overheat. However, a HOT MOTOR lamp on the dash board will alert the driver of this unlikely occurrence.

Q. Is the CitiCar really pollution free?
A. Electric vehicles are classified as inherently non-polluting vehicles by the U.S. Environmental Protection Agency. The relatively little pollution that is emitted from the power plant is usually far from populated areas and is easier to control than automobile pollution. Of course, many power plants do not burn fossil fuels, and in these cases the CitiCar is vertually pollution-free.

Q. Do electric vehicles indirectly burn just as much fuel as conventional cars via the electric power plant?
A. No, because fuel-burning power plants which generate electricty for the CitiCar can operate more efficiently than small internal combustion engines, the CitiCar's actual fuel usage is only a fraction of that of an average sub-compact.

Q. If millions of electric vehicles were used around the country, wouldn't this cause black outs and brown outs?
A. Surprisingly enough, no. Electric vehicles would most likely be recharged at night during off peak periods, when utility companies have sufficient capacity to recharge many millions of electric vehicles. In this way, power plants will operate more efficiently and electricity rates may stabilize.

Q. Could The CitiCar be powered by solar energy?
A. Once the people of our country develop the technology to inexpensively convert solar energy into electricity the CitiCar batteries could then be recharged by a solar charging station.

Q. Can electric vehicles be made to go faster and further?

A. Yes, but at a much greater cost. We have designed the CitiCar based on a comprehensive survey that urban traffic moves at an average of 28 miles per hour, and that most 'second cars' are driven only 5-40 miles per day.

Q. Is the CitiCar as safe as the average small car?

A. The CitiCar is equipped with seat and shoulder belts and most other safety equipment required by law. It is constructed on a rugged aluminum chasis and has a tubular aluminum body support structure surrounding the passenger compartment. Because the CitiCar will not be used on interstate highways, the possibility of a high speed collision is eliminated. We feel that these features and the fact that the CitiCar will be used only in low speed areas make it one of the safest small cars on the road today.

Q. What about insurance?

A. Insurance should be no different from any other compact motor vehicle. In fact, because the CitiCar will be used only at low speeds and for short-distance driving around town, we think rates for this vehicle will someday be less than for cars driven at highway speeds and for possible hundreds of miles per day.

Q. What makes the CitiCar a good investment?

A. The CitiCar is a good investment because of its low operating costs, low maintenance costs, and anticipated low depreciation.

Q. Will the CitiCar depreciate as fast or as much as a conventional car does?

A. We think not. The CitiCar's frame is constructed of corrosion-resistant aluminum. The body is of rust-proof cycolac ABS, with the color impregnated throughout the material. Also there is no internal combustion engine with its associated support systems to require repair or replacement. For these reasons, the CitiCar should retain more of its value over a longer period than a conventional car.

Q. How much maintenance does the CitiCar require?

A. Much less than for a conventional car. The CitiCar has no spark plugs, points, mufflers, radiator, valves, rings, carburetor, anti-pollution controls, or transmission. The batteries are the most important part of the CitiCar and should be checked weekly. (Consult your owner's manual for correct procedures.)

Q. How much battery maintenance does the CitiCar require?

A. Approximately 15 minutes per week to refill the batteries with distilled water.

Q. How long will the batteries last?

A. With proper care in accordance with the owner's manual, the batteries should last from 12,000 to 18,000 miles, under normal use.

Q. What is the cost to replace a set of batteries?

A. The current suggested retail price of a set of replacement batteries is about $320.00.

Q. How do the CitiCar batteries differ from regular car batteries?

A. These heavy-duty 6-volt batteries are designed for hundreds of recharging cycles, which electric vehicles require.

Q. How will I know when my batteries need recharging?

A. The CitiCar's voltmeter will indicate approximately when a recharge is necessary.

Q. How do I recharge the batteries?

A. The CitiCar is equipped with a built-in on-board charger. The batteries may be recharged by simply plugging the charger cord into any standard 110 volt household outlet.

Q. How long does it take to recharge the batteries?

A. Usually overnight, depending on the state of battery discharge, in turn, depending on daily mileage.

Q. How does the cold weather affect the CitiCar?

A. The efficiency of the batteries decreases proportionately to the temperature drop. If the batteries are kept in a state of charge during non-use, loss of battery efficiency can be minimized.

Q. How much does an average battery recharge cost?

A. About 25 cents, depending on local rates. The CitiCar SV-48 will go about three city miles on one KWH of electricity. Consult your local utility company to compute the per mile cost of operating a CitiCar in your area. Also, ask if your utility company sells off-peak electricity at a cheaper rate.

Q. Why not attach a generator or alternator to the CitiCar in such a way that the batteries can be recharged during operation?

A. This has not been shown to be an effective way of increasing range because more energy is required to turn the generator than is won back.

Q. Is there a chance that my CitiCar could run out of charge while on the road?

A. Not very much, unless you have forgotten to recharge the CitiCar the night before. However, if the CitiCar does run out of charge before you return home, (perhaps you had to run an unexpected errand at the end of the day), by simply resting for 15 or 20 minutes, the batteries will recharge themselves enough to get you a mile or so further.

Q. Is air-conditioning available?

A. No, this would cause too much of a drain on the batteries. However, because the CitiCar has large side windows and because there is no engine heat to leak into the passenger compartment, air conditioning should not be needed.

Q. Suppose I drive my CitiCar for 20 or 30 miles in the morning; can I charge up the batteries for an hour or so during lunch before going out again in the afternoon?

A. Yes, indeed.

Q. I have to drive thirty miles to work every morning. Could the CitiCar meet my commuting needs?

A. If your employer will find you a place to charge up the CitiCar during the day, you should have enough charge for the return trip in the evening.

Q. Why should I buy a CitiCar instead of a small similarly-priced sub-compact?

A. In addition to the fact that the CitiCar is a good investment, an electric vehicle is inherently pollution-free and it can be operated independent of the available supplies of gasoline. Energy independence is one of our country's greatest goals and everyone must do his part to help.

Q. Who can service my CitiCar?

A. Any authorized Sebring-Vanguard, Inc. dealer. The CitiCar is designed so simply that many owners will find that they can perform most service tasks themselves. Technical assistance is always available through the Customer Service department of Sebring-Vanguard, Inc.

Q. Are replacement parts available?

A. Yes, at any authorized Sebring-Vanguard dealer, or at the Sebring-Vanguard National Service Department, Sebring, Fla. 33870

Q. What about the motor?

A. The electric motor is a heavy-duty 3.5 HP series wound G.E. motor, designed to last for many years. Very little maintenance is required.

Q. Where can I buy a CitiCar?

A. At any authorized Sebring-Vanguard, Inc. Sales and Service dealership. Contact the National Sales Office of Sebring-Vanguard for the name of the dealer nearest you.

CitiCar tomorrow's transportation here today!

5/75

Mr. **Beaumont.** One of the things I would like to say about batteries right this minute is it is definitely a myth that the lead battery cannot provide transportation, personal transportation, for people-moving today. As far as I'm concerned, it's the most abundant economical source of energy for transportation that probably exists on the globe today.

Furthermore, in the event the nickel-zinc couple should come onstream in 2 or 3 years, there is no reason in the world why that battery could not be installed in electric vehicles that we hope to build under this demonstration program.

Electric motors and controllers draw energy to propel themselves. They can draw it from nickel-zinc, lithium-sulfur, booze, you name it. The point is that the battery gives out current which turns on the electric motor, so it doesn't matter if we should build a dozen vehicles of various categories during the next few years. When nickel-zinc comes onstream, and, frankly, I think it's more like 5 to 7 years, rather than 2 or 3, we'll just put it in the cars that are out on the road right now.

The film that I brought is a 5-minute film, which I don't think I'm going to be able to show unless we have someone who can operate the projector. There was supposed to be someone here.

Mr. **McCormack.** We are working on that matter.

Mr. **Beaumont.** What it does show is the actual production of vehicles; being driven in areas where they're utilized, and so on.

If we do have someone capable of operating the projector, while I'm speaking I can show it.

What I'd like to say, gentlemen, is right this minute in this room there are people capable of producing vehicles. As you will see in the paper, there are five categories of electric vehicles available today, just five.

Mr. **McCormack.** We have a projector on the way, and will have an operator here in a couple of minutes.

Mr. **Beaumont.** Great. As soon as the film starts I'll stop talking.

Mr. **McCormack.** OK. Please go on then to that.

Mr. **Beaumont.** The five categories are the small current cars, minitrucks and minivans, larger trucks and vans, and buses.

What should be done is the Government fund the purchase of a number of vehicles of each category. The reason for this is most all the expertise that lies in the electric vehicle industry today rests in the hands of a somewhat esoteric group of perhaps 12 to 18 innovators, or manufacturers.

It is true that our company has sold and delivered over 2 million dollars' worth of electric vehicles since we began production in May of 1974. But if you can imagine, the horrendous circumstances that we've had to go through to exist these past 2 years because of lack of capital, because of lack, of course, of any Government program to assist us in our original R. & D., the money markets, lack of credibility on the part of bankers, dealers, customers, and so on.

What we have done is undertaken a gigantic educational process. We cannot do it alone. I think we are going to make it without Government help. I think our company has passed the stage of "if we're going to make it." We're operating right now in the black, establishing a nationwide network of dealerships. We have approximately 108 dealers as of this sitting. I don't know how many of them are going to be good dealers, but if a small percentage of them do, and reorder, our production facilities can hum.

If you're going to spend Government money to enhance and further advance electric vehicles, you've got to know what you're doing and what's involved.

In the paper, I suggest part of the funds should be utilized for a quasi-administration, composed of people who are knowledgeable in the parameters of electric vehicles—where you can go, where you can't go. This administration, which should take only a small percentage of the funding, would be able to market the vehicles; would be able to locate the companies that have the talent and the ability to put together the numbers that you may decide to have made. They would be able to market the cars, perhaps educate the public, which we're doing now. This administration, outside of Government, should have the responsibility to make your program work. It can be under ERDA to some degree, but please don't appropriate $120 million to filter into a bureaucracy that does not understand the basic facts involved in marketing and servicing automobiles, whether they're electric or gas.

Making and selling a car is a world all its own. Once the car is sold you have an after-market—it must be serviced; parts must be available. If a customer is down in Belleville, Ill., and he needs a part, he has to have a place to go and get that car working.

I cannot see ERDA, as it's set up right now, being able to take the program from inception and go through all the stages necessary to get this demonstration program on the road.

I am sure that the innovators here, and the people who can perhaps make 500 of these cars or a thousand over a 2- or 3-year period, they don't have the money to do it. They're precluded from funding. It's speculative. What bank today is going to give a line of credit to an electric car company? Who's going to invest in an electric car company? Who knows anything about electric cars? The Government doesn't; ERDA doesn't; but we do. I say "we," and the innovators, and the people who have come here to testify. We know what can be done. So let us help you to help the whole concept of electric vehicles, come perhaps as much as a decade sooner than they would anyway, because as sure as you're sitting there, we have to go to electric transportation. We have no more oil. So it's not when, if, or maybe, or feasibility, or R. & D. studies for the next 5 years. Build the damn cars now. Get the money out. Let the public be familiar with driving electrically. Let these cars be serviced. Let them break down. OK. But let people's butts move electrically, because we have no other way to go.

Now, if the film's ready.

Mr. McCormack. We will look at the film, and then I have some questions.

[Film shown.]

Mr. Beaumont. This film was made and paid for by the U.S. Information Agency. The purpose of the film was to show technology in America and how advanced we are in the state-of-the-art of electric vehicles. My understanding is 102 copies of this film have been sent to foreign countries.

The superstructure of this car weighs 96 pounds. It's comprised of 197 different parts. It's completely aluminum.

Now, after 10 or 15 years, when the car has outlived its usefulness, that aluminum can be remelted and made into new parts. It's completely recyclable.

The cable you see is comprised, of course, of copper. Virtually all the copper in the vehicle can also be used for decades.

The batteries that the gentlemen are putting in the car are lead-acid batteries: electric vehicle batteries. Over 80 percent of the lead, which makes up the vast majority of the weight of those batteries, can be recycled and reused to make new ones 3 years or so after they have given up their lifespan.

A lot of this planning and thinking went into our concept of the city car, people-mover.

What we're attempting to show is that the technology exists now. If a little company like us can do this, and build, by the way, a thousand cars since last May and sell them, with some assistance from you people, perhaps another six or eight companies can gear up and do the same thing and perhaps make a better car than we do.

The plastic body that the car is comprised of is of an ABS material, which is the same material that is used in typewriter cases and football helmets.

After 10 or 15 years' usage of the vehicle, all the body of this car can be reground up into new resins. These resins can then be recycled to make typewriter cases, shelving, terrace tables, and so on. So what we're obviously stressing here is that the majority of this vehicle is made, not to throw away in the junkyard about 3 or 4 years from now. We can recycle most of the components that go into it to build other things.

Incidentally, this film was made well over a year ago, and we'd really just got started.

As I said, over $2 million worth of these vehicles have been sold to dealers and the public since last May. The people who are buying the cars are using them daily. Perhaps you've seen them in your neighborhood. We have a list of over 600 owners right now who will stick up for this car like you wouldn't believe. It's almost like a club. In fact, it's reminiscent of the way the Volkswagen was twenty-odd years ago. People want this form of transportation. They're waiting for it. The public is not stupid. They know we're running out of oil, and they know they're spending a fortune to operate their current vehicles. They see a chance to save a buck here.

In your bill—I don't know who wrote it or who put it together—all the provisions of the bill make so much sense that we're just flabbergasted at the thinking that went into it, and you're so right. That's the beautiful part of it. There's very little in the bill that we can complain about.

So we had a struggle. I say you people can help other companies and perhaps they won't have to go through what we've gone through, and not even through a subsidy, because for every car you people build, somebody's going to drive it and not use gasoline, and somebody will pay for that car.

I've got $68-odd million in my proposal for you to spend on demonstration programs, but you're going to get the money back. The proposed administration will see to it that you get that money back, by lease, or by ultimate sale—you name it. So it's not a subsidy. Nobody's looking for a subsidy. But help the people out there who can't get a dime to engineer and work until 12 o'clock at night and make a better car, even if it's a conversion, no matter what it is. Companies are not going to spend money for R. & D. on electric vehicles with no market. They're just not going to do it today.

Watch this finale. [Indicating slide.]

Thank you.

Mr. McCormack. Thank you, Mr. Beaumont.

I want to, first of all, congratulate you most sincerely on your accomplishment, going out and doing it. I think you have lived out a dream of an awful lot of people, and I am thrilled, literally, with what you have accomplished. I could not be more generous in my praise, no matter what I said.

Mr. Beaumont. I really believe you mean that, too, and I'm very grateful.

Mr. McCormack. I just want to say to you, Mr. Beaumont, and everybody else here, that I put two amendments in yesterday for Mr. Ullman's energy tax bill, one of which provides accelerated depreciation for manufacturers of electric cars, and another one which provides for up to a $750 rebate for purchases of electric cars.

Mr. Beaumont. That's unbelieveable.

Mr. McCormack. Both of those amendments will be submitted for consideration on the floor when the bill comes up for consideration next week. So we are trying our best to help.

Now I want to get back to the theme that you are expressing, and you are expressing a troubled attitude with implementation of this program.

First of all I want to thank you for your comments about the bill, because I was the guy who wrote the bill, along with Dr. Ratchford here, and the services of Dr. Currie. So we appreciate that.

Now let's get down to one point that is real tough in this thing, that I recognize as being tough, and that you alluded to, and that is: How do we really make the bill work?

If we purchase 5,000 or 10,000 vehicles and lease them out all over the country, we are going to have cars scattered from every nook and cranny in this country; and if we go out to from 10 to 20 different manufacturers to get them, we are going to have, for instance, in Puget Sound, or northern Minnesota, or northern Maine, or the middle of Wyoming, electric cars made by one manufacturer or another.

How are we going to handle maintenance under those circumstances? Do you have any suggestions?

Mr. Beaumont. Of course. And it's beautiful to hear you say that because, as I said, the bill was worded properly and right.

Now, you're asking probably the most important part of the whole program. These cars cannot be orphans out in the field. That's why I say we have to have a separate administration to handle the funding. Now, when I say "handle it," I go into this on page 2 of my paper, and I mention part of how it should be done.

But the reason I suggest this administration to handle this is because, in essence, this administration would handle the vital and necessary functions which auto dealers now provide for their manufacturers. The point is the agency could be the buyer. Each procurement—let's assume you bought 1,000 or 2,000 cars from us—we would channel them through this agency. We would also stock this agency with spare parts. We would teach this agency how to service the vehicles. Let's say they bought 500 cars from Bob Aronson, which are conversions. This agency would buy and contract with Aronson for 500 vehicles. He would stock them with parts and train their people on how to service the vehicle. The administration would be responsible for procuring, writing specifications based on parameters that can be based on energy storage today, and actually handle physically the procuring, the leasing, the rental, the sale to Puget Sound and other distant areas.

But if we sold a group, or a car, to Puget Sound, somebody in the administration would know how to service the vehicle. We would then impart that knowledge to the customer by way of a maintenance manual, by way of a parts list. We could contact one of our dealers. We may have a dealer there who could service these cars. Someone else may have a dealer. Elkhart may have a dealer in the area or Chillicothe, Ohio.

The administration that I say is tantamount to the success of this program would be responsible for the questions and the important part of the program, the aftermarket. That would be the administration responsibility, and I cannot see anyone in ERDA handling the day-to-day mundane problems in connection with the customer whose car is down. That should be the responsibility of this administration.

Mr. McCormack. I think the administration is going to have to come within the agency, but they can set up a special agency.

Mr. Beaumont. Certainly it should be under the auspices of ERDA, and working with ERDA, absolutely.

Mr. McCormack. I understand.

Mr. Beaumont. It's like a dealership, Mr. McCormack. It's like a gigantic car dealership. You should have nuts-and-bolts guys in this organization; have people running it who know what you can do. No pie-in-the-sky stuff. "We want a car that will go 80 miles an hour for 200 miles. Now, does anybody want to bid on this?" Well, that's ridiculous. You don't even need bidding.

Dr. Thornton was absolutely right when he said competitive bidding will defeat the purpose of this program. Give the innovator a chance to make some cars.

Mr. McCormack. Thank you.

Mr. Thornton, do you have a question?

Mr. Thornton. Thank you, Mr. Chairman.

I just want to say I am tremendously impressed with the work that you have accomplished. The lightweight body and careful selection of materials show a great deal of thought.

If I may ask one specific question which occurred to me on the film. One of the great problems we had was finding some way of sealing windows in the vehicles that we produced, and I noted that you did not have windows in the vehicle.

Do you have a screen, or what was your method?

Mr. BEAUMONT. I'm not sure if the pamphlet, the little advertising piece that was attached to my statement, shows the windows or not, but we have a removable frame on both doors that fits rather snugly, protects the occupant from rain. It's sort of like a tonneau window that was on the old M.G. sport cars. It's removable. This fall, however, we will have a complete door and an enclosed window, more conventional and probably more acceptable, than we have now.

The most difficult thing, as Mr. McCormack said, was getting business, to exist. Now product improvement, of course, is tantamount to our success.

Mr. THORNTON. I do want to thank you for your very interesting presentation, and the tremendous amount of work that went behind it.

Mr. BEAUMONT. I've been carrying the torch for 8 years, Mr. Thornton.

Mr. MCCORMACK. Mr. Hechler.

Mr. HECHLER. Your enthusiasm is infectious, and I congratulate you on your presentation. I agree with everything you said.

Let me be the devil's advocate for just a minute here, on the entity that you suggested. I feel very strongly, and share your feelings about the need for such an entity. However, when the Congress felt exactly the same way about the Postal Service we moved in that direction, and I think we got our fingers burned a little bit in terms of the results.

I am not asking you to solve the problems of the Postal Service. I am simply suggesting that it is very easy to say that there are a lot of regulations in Government; therefore, we are going to have to set up an independent agency that simply has the money, to go and run with it. We have an obligation to make sure that this money is not foisted, corrupted, and frittered away, and you have a real double-barreled problem there in setting up such an independent agency, and assuring that it really does what you want it to do.

Mr. BEAUMONT. Well, the people who voted for you, Mr. Hechler, voted for you because you know what you're doing, or else you wouldn't be where you are today.

My point is this: There are half a dozen men in this country now working for corporations who are familiar with all the ramifications involved, and all the parameters, and all the possibilities in current electric vehicle technology. The guy who runs the program, the administrator, the man who runs it, has got to be knowledgeable. Now, if you get that man, your program's going to work. It's as simple as that. Just like the guy who's running the show now, a guy named Ford. If he does a good job, we're going to do a good job, all of us. It works the same way with this quasi-governmental administration. The rules will be set up by you. You'll lay out the guidelines. ERDA will control it. But let the guy handle it who knows what he's doing. That's the whole point.

Mr. HECHLER. OK. Just spell it out a little bit more in the coming weeks, because this is one of the questions that we are going to be asking, just exactly how is this going to operate.

I agree with the goal. I agree with the concept. But I just hope you can spell it out a little more, in such a way that we can move toward it.

Mr. BEAUMONT. OK.

Let's get down to specifics, now. I've got my company running to the point where I can disappear. You'll note, if you read my paper, it is not a commercial-promoting Vanguard. It's an attempt to spend this money fairly and get the most back. I'm not pushing ourselves in. I'm willing to spend the time to talk to you about these things, and how it should be done, and I'm going on the basis of 20 years' experience as a car dealer. I was with Chrysler Corp. since 1955. I gave up the agency in 1967. So I know what's involved with selling and servicing vehicles, and administrating the problems inherent in it. I'll be glad to spend time with you and go over it in any way you want: in writing; I'll come up; we can sit down. But if you're going to spend money spend it right and let us help you with it.

Mr. HECHLER. All right. All of us, I think, can learn more through our eyes than through our ears at this point, and I think what you can provide the committee would be extremely helpful.

Mr. BEAUMONT. I'll take your suggestion under advisement.

Mr. HECHLER. Thank you.

Mr. McCORMACK. Thank you very much, Mr. Beaumont. We very much appreciate your testimony, and we're looking forward to working with you in the future also.

At this point we're going to recess the hearing until 2 o'clock this afternoon.

Mr. BEAUMONT. Thank you.

[Answers to additional questions submitted to Mr. Beaumont follow:]

STATEMENT OF
ISSUES AND QUESTIONS

by

ROBERT G. BEAUMONT, PRESIDENT
SEBRING-VANGUARD, INC.

TO THE SUBCOMMITTEE
ON
ENERGY RESEARCH, DEVELOPMENT, AND DEMONSTRATION
ON THE
ELECTRIC VEHICLE RESEARCH, DEVELOPMENT, AND DEMONSTRATION
ACT OF 1975 (H.R. 5470)

JULY 25, 1975

REPRESENTATIVE MIKE McCORMACK
SUBCOMMITTEE CHAIRMAN

ELECTRIC VEHICLES
ISSUES AND QUESTIONS

1. There is a need for a Federal role in aiding the electric vehicle industry if Government wishes to accelerate what ultimately has to come anyway.

2. In essence there is no electric vehicle industry as such other than that which is in the planning stage and almost certainly dependent on financial assistance coming from some area. There are some small firms who have been trying to enter the EV market via the conversion of conventional ICE vehicles to electricity. Their efforts so far have been fruitless concerning actual production and sale of vehicles other than on a very limited basis has not taken place. While it is true that AM General Corporation, a wholely owned subsidiary of American Motors Corporation, has a contract to produce 350 postal vans, its future planning much beyond that is somewhat clouded. The Battronic Corporation currently makes larger vans in very nominal quantities. Otis Elevator was considering an electric-mini people mover. We believe those plans have been shelved. Electric Fuel Propulsion has yet to deliver its first Transformer I. CH Waterman Industries recently received a temporary exemption from Federal Regulations to import and convert the DAF car. This small concern also has yet to deliver its first converted DAF. It can be summarized quite succinctly that while many believe an EV industry is coming, noone can seem to say exactly when, what form these vehicles will take, and just who is going to finance such an industry.

A. Therefore, the current growth rate is proceeding extremely slow. The rate can only be accelerated when and if companies capable of manufacturing are willing to accept the inevitable, i.e., gasoline has to be on its way out as a power source for personal transportation and electric drive must take its place.

B. Basic limitations of the industry involve market acceptance, technology, but most of all, capital, which can be channeled towards a viable product. Business today must be sure that every dollar spent will return more than a dollar in actual sales. There seems to be a decided lack of entrepreneurial effort on the part of our major corporations. Certain funds that may become available under a Government program will definitely be risk. That is because electric vehicle technology has had a long dry spell over the past 50 or 60 years. If a Government Bill results in helping a given company to prosper, it wouldn't take long for others to jump in with both feet.

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3. Obviously, competitive bidding will be extremely difficult. If, indeed, there were an industry existing, bidding might be possible. Part of the purpose of a Government program would be to help in the initial financing of the obviously low capital companies who have the ability to actually produce vehicles. The unusual circumstances that will have to surround this program are that it may be necessary to get the vehicles from few available sources, thereby eliminating the traditional Government procurement procedures.

B. Loan guarantees would not provide much of an incentive for small companies to raise capital necessary for the production of vehicles. Since the loan would have to be paid back, the companies would have to charge exhorbitant prices for vehicles procured under the demonstration program. This would be necessary to cover nominal interest costs, start-up and developmental costs, as well as the necessity of actually paying the loan back. It must be faced: in some instances the Government would have to totally fund purchases under certain parts of the program.

C. Once again, traditional procurement procedures may have to be waived in connection with patent provisions, delivery schedules and contract penalties. You might be able to continue these traditions if you were dealing with General Motors or General Electric. Small businessmen who, most likely, should be the main participants in the demonstration program, cannot be too tightly controlled on contract specifications, especially those that could destroy them financially.

D. Since the number of electric vehicles that can be made available are limited to: small people movers, small vans and pick-ups, large vans, trucks and buses, it would make sense that vehicles in all price ranges and sizes should be purchased. The largest purchases should be made in the area which would portend greatest ultimate usage. If the traditional role that a Government program should not directly benefit a private corporation financially cannot be discarded, we believe the demonstration effort will be in trouble before it is started.

E. The productive capacity of large automobile manufacturers is currently wasted. Thousands are idle because the industry has finally priced itself out of the market and Detroit has lost

Continued.........

much of its glamour. None of the Big Four is willing to gamble on another "electric Edsel", therefore, only smaller business would be interested in participating in a demonstration program. It is doubtful that there will be a large choice of just who participates in building EV's. There are very few in the country who even know how. If it is Congress' desire to assist General Motors and Ford getting into the electric vehicle business, that is one thing. It would be more effective to assist small business in their efforts to produce vehicles under the program. If small business can prove to Detroit that, indeed, a market exists and the technology to make cars is in hand, the larger companies will be forced to become serious.

F. One of the primary reasons for only four companies making motor vehicles in this country is the Motor Vehicle Act of 1966. All of these regulations were designed and created solely with the ICE vehicle in mind. There are perhaps a dozen good-sized corporations who would like to make various forms of energy-conserving, small, maneuverable forms of transportation. Some would not even be electric. Federal Motor Vehicle Safety Regulations as promulgated by the Act have completely shut the door on these efforts. Safety has precluded common sense. Indeed, certain of these safety regulations would be thrown out of court because they violate every anti-trust law ever made. In effect, these regulations state that unless you make a motor vehicle like Detroit does, you may not come into the market. We do not believe import regulations could currently affect a potential EV industry.

4. There have been many surveys conducted in connection with consumer acceptance of a limited-performance vehicle. Indeed, Opinion Research Corporation of Princeton, N. J. has concluded that over 57 million Americans would consider purchasing a limited-range, low-speed electric vehicle providing it was priced under $3000. The EPA Report of October 1974, Impact of Future Use of Electric Cars in the Los Angeles Region, stated that over 2 million electric vehicles of the kind now available could be utilized in the Los Angeles basin. The consumer is ready, willing and able to purchase an electric vehicle that will provide him with economical transportation. Obviously, the consumer will be further spurred as a Government energy program emerges, gasoline increases in price and as more vehicles are actually in daily use.

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5. The main barriers to the introduction of electric vehicles is simply "out of sight, our of mind". Detroit has made a career of orientating people to gas buggies and that lack of a suitable battery precludes EV's at this time. You don't "unbrainwash" this type of powerful implant very easily. Congress may indeed help the EV industry by spending money undoing this erroneous image. Money could be well spent in showing EV's in actual use. Other problems are certain prejudices against introduction of EV's. Some states penalize buyers by increased licensing fees. Others, because they have no rules covering EV's, have a tendency to ignore them but, in general, the fifty states are beginning to look favorably upon EV usage. There is little that can be done to affect utility rates. However, as we reduce our consumption of oil to fire generators, rates should halt their long climb upward. Many power companies are beginning to promote off-peak usage and are actually installing dual meters: peak and off-peak. EV's are destined to utilize the low off-peak meters. If the circling of cities by superfast highways does slow down, EV's will have less of a problem keeping up in traffic. But, in reality, the vast majority of EV usage is in urban areas where the posted speed limits do not exceed 35 MPH. In essence, there are no serious barriers to EV introduction, just a serious lack of understanding, capital and product.

6. Maintenance facilities for EV's already exist. All 25,000 automobiles dealers currently employ at least one technician trained in the electronics of a conventional automobile. Electric circuitry in EV's is certainly no more complicated than in ICE's; indeed, in many instances, less. Not only do maintenance facilities already exist, but the above-mentioned off-peak power is a vast reservoir of energy available to recharge tens of thousands of EV's.

7. We believe National goals could best be met by the cooperation among large and small manufacturers. Even now, large companies are working towards component production improvements. Available capital will certainly spur more intercourse between the large and small companies. We believe both are needed.

8. The current state of the industry definitely needs time. We believe a four-year program, and perhaps an additional 40 million dollars, could be more fruitful. Phase One of the program (Conventional Chassis) would appear to be somewhat of a dead end. No serious numbers of vehicles will ever be able to invade the market because

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the economics of conventional converted vehicles preclude large distribution. However, in view of the current state of the industry, it may be necessary to finance production of a few thousand of this type vehicle mainly for exposure purposes. The current energy source does not permit the luxury of excess weight inherent in ICE's. However, the engineering, research and development, and just plain hard work that will go into converted cars is bound to produce worthwhile innovation and knowledge. It would appear that 10,000 vehicles could be procured within three years from the inception of the program. The fourth year mentioned above would allow a cushion if more time is needed.

9. The very fact that speed kills, coupled with the relatively slow speeds of electric vehicles, augers well for EV's when it comes to safety. In areas connected with glazing, i.e.,glass, lighting, bumpers, tires and wheels, etc., EV's should have no problem meeting safety requirements, however, the tedious regulations in force as to side door impact, roll-over protection and other requirements that must add overall weight to EV's could seriously affect their development. Trade-offs of low speed and short distances will have to be made versus stringent "crash worthiness" regulations so as not to preclude the EV energy source from carrying a payload rather than regulatory dictated weight.

B. The weak solution of sulphuric acid is ordinarily not dangerous and a simple rinsing with water would eliminate damage to person. The only real hazard, if some of the acid should spill, would be in increased costs for clothing. It definitely would damage fabrics. One aspect of potential hazard in the recharging of EV's would be severe gasing at high charge rates. Without proper ventilation in cases like this, there is potential for hydrogen explosion. This can be precluded by current charges that are available and that will be developed.

10. For long distance transport, especially in connection with the interstate shipment of goods by truck, we are facing a serious problem. Also, air travel is in danger of "running out of gas" in the foreseeable and very definable future. A choice soon has to be made. Shall we conserve our dwindling supply of gasoline to add an additional decade or two to ICE trucks and airplanes? If so, a choice must be made shortly as to who is going to get the gasoline, personal transportation or the trucking and airline industries. There will not be enough for all three. Therefore, the logical approach would be to convert to electric drive as soon as possible

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in the areas of personal transportation, as well as other mass transit vehicles. Petroleum will have to be used for long distance transport far into the future. Electrified roadways makes some sense, however, fixed rails would still not give individual mobility and it is doubtful there would be enough money to make sufficient of such roadways to lessen our dependence on petroleum. We may be able to take away the gas guzzling chariot and replace it with small battery-powered people movers, but there is a limit in attempting to direct exactly where people may travel.

B. If a fraction of the monies expended on the Morgantown project (currently a fiasco) would have been spent on a few thousand simple electric golf carts, it would already have accomplished more than the hundred million dollar flop will ever do. If sufficient battery-powered people movers were concentrated in urban areas it would, in effect, be an electric mass transit system. Therefore, part of the program should encompass selecting a city and flooding it with the controlled use of hundreds of the type vehicles that could be manufactured under a demonstration program.

C. Most fuel cell work has been toward the possibilities of creating electricity directly from hydrogen. We believe that the Congress should incorporate further research on the fuel cell as an alternative to petroleum and, indeed, think seriously about replacing petroleum as the fuel source for the long distance trucking industry and air industry with hydrogen.

11. The basic objectives of technology demonstration should be based on the adage that "a picture is worth a thousand words". Of course, the most single important criterion in planning such a program is that it does not lead to a dead end and that vehicles demonstrated would be capable of being built in volume and providing a substantial service within our transportation system. With this in mind, we continue to reiterate that the proposed EV program can best reach its objectives by a purchasing program of vehicles that can contribute quantitively to the daily transportation needs of the citizenry.

B. The only real accomplishments possible within the time frame of the EV program will be to further emphasize the very truths contained in the Bill that it is not only possible to use battery-powered vehicles within the transportation system, but practical and economical as well. This in itself should activate the en-

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trepreneurial instincts that we hope still exist in the business community.

C. If the program were delayed until battery breakthough takes place, nothing would be accomplished. The only benefits that would accrue to potential manufacturers would be perhaps a better chance to compete with Detroit item by item. This would be fruitless because our great need is for moving people in urban areas at relatively slow speeds and short distances. It would be falling into the same inescapable trap that Detroit and Madison Avenue has perpetrated on the American car buying public for decades, i.e., sex, zoom and prestige are the main reasons for motor vehicles and the transportation aspect is secondary. If we wanted to cater to this psychological nonsense, we might put a simulated stick shift in our battery-operated vehicles which may perpetrate Madison Avenue's phallic stick symbol.

D. If we try to parallel a demonstration program with battery advancements, we would be in danger of engineering EV's to death. That is, let's wait until we have the best batteries, to make the best car, do what? We are at least a decade away from batteries that may even come close to the unneeded zoom specifications in ICE's. Twenty-two million Model T's never traveled much over 30 MPH. Fifty million current ICE's, the same. What is constantly stressed here is that a gigantic educational and explanatory program is in order. People are not idiots. Their pockets have been gouged by unreasonable and cumulatively advancing costs in connection with operating their zoom machines. They are ready for a change.

E. The biggest mistake that could be made would be attempting to develop EV technology out of thin air. The ability to manufacture hundreds of thousands of battery-powered people movers has been on the shelf for decades. There is nothing complicated about it; it's just a simple question of putting all the available pieces into a transportation package that is priced within reason.

F. Everything on the horizon is mitigating toward electric drive. Gasoline is bound to be shorter in supply and higher in price. Increased usage of off-peak electricity for recharging could eventually level off the KWH price. Better utilization of generating capacity, without increased personnel and capital expenditures, primarily through 24- hour-per-day load requirements would not only keep the cost of electricity down but create extra profit our utilities need to keep up with the nation's electricity requirements. Obviously, ICE' will continue to rise in price. EV's, conversely, as volume increases and mass production takes hold,

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should be able to lower and, at the least, maintain competitive pricing advantages.

2. Hybrid vehicles is one area that H.R. 5470 could devote a portion of this funding. It has long been figured that the day will come when there are two types of motor vehicles, the long distance high-speed gasoline vehicle and the small city electric. While an efficient hybrid may be an interim transportation form inevitably it would lead to a dead end. Two systems in one will be inherently expensive, noisy and somewhat polluting. Let us all hope that the automobile market can be made up of the family gasoline vehicle for the longer, faster haul and the second car, battery-operated, for the city car. However, if an efficient, quiet hybrid vehicle, capable of being mass-produced for under $5000 could be developed through the expenditure of one or two million dollars, it would be worth considering under H.R. 5470.

While the Witkar program in Amsterdam has had problems, reports are beginning to flow through that it is enjoying some measure of success. A very real and important contribution could be made under the program if certain sites were selected and a system similar to Witkar was put into effect. If sufficient small electric people movers were available in certain downtown areas, it would have the multiple desirable effect of ameliorating traffic congestion, noise and air pollution. Certainly, this is not something to be taken lightly.

Those who say that a problem of "road mix" of EV's with ICE's exists are completely erroneous. The vast majority of locations where current and future EV's will be utilized are already suffering very congested conditions. Bicycles, Toyotas, EV's, motorcycles, Cadillacs, and all sizes of trucks are currently competing for space on the nation's roadways. Over 80% of all the above-mentioned vehicles are operated daily on roads where the posted speed limit does not exceed 35 MPH. Are we to arbitrarily say that Massachusetts Avenue in Washington, D. C. is reserved for Cadillacs and trucks from 8 A.M. to 10 A.M., then bicycles, motorcycles and EV's may use the Avenue from 10 A.M. to 12 Noon. From 12 Noon to 3 P.M. only Toyotas and Pinto-size vehicles may run. Many of the reports we read today concerning alleged problems of traffic mix are composed by minds who have been on the top floor of medieval castles whose tunnel vision separates them from the reality of actual driving conditions in congested areas where speed is impossible, making the question of safety academic. We wonder if hundreds of

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the nation's journalists who have written favorably, based on actual driving current EV's in city traffic, are suffering from delusion. If the mix problem does exist, we also question the sanity of those hundreds of people using their EV in metropolitan and suburban areas. We believe a questionnaire would be in order at this point for all who espouse potential problems in traffic mix.

The very first question would be.....have you ever driven an EV?...

Robert G. Beaumont

Robert G. Beaumont, President
Sebring-Vanguard, Inc.
Sebring, Florida
July 23, 1975

[Whereupon, the subcommittee recessed at 11:30 a.m., to reconvene at 2 p.m. of the same day.]

AFTERNOON SESSION

The subcommittee met, pursuant to recess, at 2:15 p.m. in room 2318, Rayburn House Office Building, Hon. Mike McCormack (chairman of the subcommittee) presiding.

Mr. McCORMACK. The meeting will come to order.

We will pick up where we left off earlier today, and I hope we'll be able to complete the testimony of the next two witnesses by 3 o'clock.

Our first witness is Robert Aronson, president of Electric Fuel Propulsion Corp. of Troy, Mich.

Mr. Aronson, welcome to the committee.

Again, if you would like to submit your written testmony for the record and speak from it, please feel perfectly free to do so.

STATEMENT OF ROBERT R. ARONSON, PRESIDENT, ELECTRIC FUEL PROPULSION CORP.; ACCOMPANIED BY JOHN TREPCYZINSKI, MECHANICAL ENGINEER, AND DICK McLEAN, WOLVERINE DIESEL CO.

Mr. ARONSON. Thank you very much, Mr. McCormack. I would like to do just that. I don't want to read that testimony. It will speak for itself.

[The complete statement of Mr. Aronson follows:]

TESTIMONY BEFORE THE CONGRESSIONAL SUBCOMMITTEE

ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION

Re: BILL H. R. 5470

by

Robert R. Aronson, President

Electric Fuel Propulsion Corp.

June 4, 1975

I am very pleased that you asked me to testify on the proposed Bill H. R. 5470.

The first time I came to Washington, D. C. on electric car business was in March of 1967--eight years ago. On that occasion I drove a MARS II Electric Car all the way from Detroit--a distance of 756 miles. Preceding the MARS II was an internal combustion powered station wagon with a 2000-pound 50 KW fast charger on board. The MARS II was charged every 60 or 70 miles on kilowatts supplied by courtesy of the electric utility companies along the way. The occasion was testimony before the Senate Commerce Committee on new technology which was to be given government support by way of a Bill introduced by Senators Warren G. Magnuson and Edmund S. Muskie. This Bill would have made millions of dollars available to private industry for research and development on electric cars and other forms of new technology. Unfortunately, that Bill never made it through Congress. Major corporations opposed it saying, "Let us handle our own R & D--we don't want government support". The result was that the Bill was killed, the major corporations who had complained the loudest did not pursue the kind of R & D that would have brought about alternative sources of energy and energy conversion hardware, and small businesses and individuals who, by their own testimony at the hearings, were ready to make an all out effort to develop new sources of power and new types of power plants, such as electric propulsion systems, were denied badly needed R & D funds not available from other sources.

A few months later, in October of 1967, I found myself again in Washington, D. C. on electric car business, this time as a witness to

Senator Philip A. Hart's Subcommittee on Antitrust and Monopoly, testifying on the role of the electric car in New Technologies and Concentration. While in Washington, another MARS II Electric Car was en route to Phoenix, Arizona, being driven there from Detroit, at highway and turnpike speeds and over mountain ranges, by Arizona Public Service. During Senator Hart's hearings, a very interesting statement was given by Dr. Donald Schon, formerly Director of the Institute for Applied Technology of the National Bureau of Standards. In his testimony, Dr. Schon stated that of 60 of the most important inventions of recent origin analyzed, one-half of these were attributable to inventors who worked with their own resources and that such inventors, working alone or with small companies or universities, have been and continue to be a major source of significant inventions.

Recently I spent several weeks in Japan and visited the factories of some of the Japanese companies. I was amazed to see the rapid progress they have made in electric vehicle technology. I had a meeting with a highly placed government official in the Ministry of International Trade and Industry (MITI) and was given a copy of The National Research and Development Program the Japanese Government had created to speed up the development of electric vehicles and other new technology. At that time, $13.89 million was being given to about a dozen Japanese manufacturers for research and development designed to get them into electric vehicle production--cars, vans and buses--by 1976. Of course, Japan has no petroleum reserves and the urgency of their problem is understood. But is the problem less urgent here?

Now here in Washington, Bill H. R. 5470 is being considered by this

Congressional Subcommittee whereby our government would provide funds for the purchase of electric cars to relieve our dependence on petroleum--among other things. I believe that this time the Bill will mature into legislation in spite of what major corporations might do. But if such legislation is passed, who will get the money? Will it go to Big Business by default because small firms and individuals, who are largely responsible for the real innovation in this country, will not have the staff or personnel to wade through tons of red tape and follow lengthly bureaucratic procedures with the assistance of high paid Washington consultants? Let's hope that the strengths and limitations of small firms and individuals will be properly recognized in this pending legislation.

From the time I drove the MARS II Electric Car from Detroit to Washington, D. C. in 1967 until the present time, EFP has been dedicated primarily to one thing only--the development of a highway passenger car--not a delivery van, truck, bus or golf cart.

In July of this year, EFP will begin production of our 1976 TRANSFORMER I Electric Car--a truly remarkable vehicle powered by an even more remarkable battery.

The car itself is what we now describe as "International" in size, and to my knowledge is the only electric passenger car in the world offering a wide range of luxury equipment such as automatic transmission, power steering, power brakes, power windows, power seats, power door locks, electrically powered Sky Roof, tilting steering wheel, AM/FM Stereo Radio and Tape System and many more. A specially developed battery powered air conditioner is now under development and we expect will be available within a year or two from now.

Most electric vehicles now on the market are rather spartan in nature, and this is good, as the features I have mentioned do consume electrical power and reduce the driving range of the vehicle 10 to 20%. However, many of our customers and potential customers, while wanting the comparative efficiency of personal electric transportation, do not want to give up the conveniences afforded by gasoline powered vehicles. Indeed, some of these "conveniences", such as power brakes and power steering, are now considered by many as safety features indispensable to good highway driving.

The Tri-Polar, Lead-Cobalt Battery, which powers TRANSFORMER I, has been under development for nine years and has been tested in over 70 electric vehicles during that time. It was responsible for Caltech's victory over MIT in the 1968 Great Transcontinental Electric Car Race; gave Cornell University first place in the "pure electric" division of the 1970 transcontinental Clean Air Car Race, and Stephens Institute of Technology second place in the same race. As a matter of fact, the only electric cars ever to cross the country under battery power, traveling 400 to 600 miles a day, were equipped with Tri-Polar, Lead-Cobalt Batteries.

But what makes this battery so different? The main reason is that it can be recharged in a very short period of time--to 80% of capacity in less than an hour--without damage to the plates or insulators and without overheating. This is why the Caltech, Cornell and Stephens vehicles could travel up to 90 miles on a charge at highway speeds, recharge in 30 to 60 minutes, and continue on and on, around the clock. No other battery has ever been able to perform like this.

U. S. Patent Number 3,518,127 describes an advanced version of this battery which, we expect, will be in production within the next year or two. Laboratory tests indicate a 20% inprovement in energy density (useful stored energy per pound of battery) and recharge time. We are hopeful that it will be possible to obtain an 80% recharge in 22 minutes. And, a new patent application is now being filed covering a significant improvement over the present patent which will further increase energy density and reduce recharge time.

A simple fact of life is that a Fast Charge Battery, to be of any value to an electric car, requires a Fast Charger. EFP has developed two types of Fast Chargers: A "Charge Station" which operates on electrical power generated by an electric utility company such as Detroit Edison; and a Mobile Power Plant which operates on gasoline power generated by a gasoline engine.

Of course, here I should say that Fast Charging will, in our opinion, be done only in the daytime. At night, the electric car owner will plug his vehicle into his wall receptacle at home for an overnight slow charge, utilizing the car's built-in Slow Charger.

But Fast Charge Service in the daytime will be a must for satisfactory electric car operation. Even though an electric car owner may only drive his car 30 miles a day in normal commuting, there will be times when he will want to be able to drive it over 100 miles and this is where Fast Charge Service comes in. And there will be times when he will run out of charge on the highway, as we sometimes run out of gas now with our present cars, and Emergency Highway Fast Charging Service will be essential.

The electrically powered "Charge Station" can provide rapid charging but has several disadvantages. First of all, it is stationary, fixed in one location and tied into high power electrical lines--220 volts, 3-phase, 300 amps. Secondly, it requires huge amounts of electrical power--30 to 50 Kilowatts--over a very short period of time. If a thousand of these Charge Stations were all charging at once in a given area, it would severly tax the already overtaxed capacity of electric utility companies in the daytime, especially in summer months when air conditioners are in use in homes, office buildings, etc. The Charge Station, therefore, is not the answer to wide spread demand for Fast Charge Service.

On the other hand, EFP's Mobile Power Plant seems to be, in our opinion, an ideal solution to the problem. It consists of a gasoline engine, a generator which is driven by the engine, and a 2-wheel trailer on which the engine and generator are mounted. When the engine is started, the generator supplies enough electric power to charge an electric car to 80% of capacity in less than an hour. As a matter of fact, a 10-minute charge will supply an electric car the size of TRANSFORMER I with enough energy to enable it to travel at normal speeds for 15 miles; or a 20-minute charge for 30 miles, in typical mixed expressway and city traffic driving.

The Mobile Power Plant lends itself nicely for use at gas stations where gasoline is available and engine repair technology not foreign. The logical place to refuel a gasoline powered car is the gas station, day or night. The logical place to refuel an electric car should also be the gas station--but only in the day time when one expects to travel in excess of the usual 30 to 60 miles in, say, a typical commuting mission.

Gas stations can also provide Emergency Highway Fast Charging Service by towing the Mobile Power Plant to a point on the highway where someone's electric car has "run out of juice". In a few minutes the car can be recharged and on its way again.

And, gas stations can rent Mobile Power Plants to electric car owners who want to take long trips in their cars. A Mobile Power Plant, in operation, hitched up to the back of TRANSFORMER I will enable that vehicle to travel up to 1,100 miles a day at better than 20 miles to the gallon of gasoline (according to preliminary tests).

As a bonus to the gas station that owns or leases a Mobile Power Plant, the apparatus can be used for emergency lighting and power in the case of electrical "blackouts" or "brownouts". It can also be used for welding and operating electric tools.

But some may ask, "Aren't we defeating the purpose of electric cars when we use gasoline to charge them?" The answer to that seems to be quite simple. 80% of all charging will be done at home at night, according to our calculations. 20% charging on Mobile Power Plants would stretch out available gasoline supplies five-fold. Moreover, the convenience of daytime Fast Charge Service would greatly enhance the value and utility of electric cars and therefore result in greater market acceptance of personal electric transportation.

To summarize the present, the EFP highway electric car embodies all the safety and convenience features of the modern internal combustion vehicle. We need not apologize for it. It will handle 90% of all city and suburban driving missions. And because of its economy of operation, a person driving 60 miles a day in a TRANSFORMER I--or, 20,000 miles a year--can save well over $1,000 a year in fuel and maintenance when compared to driving an internal combustion car the same distance.

The 9-year development program I have briefly described, which has led to our present plans for production, could all be solidified into a more secure and lasting program with the passage of H. R. 5470 and with participation of small business firms such as EFP.

Now, I would like to invite you to see the TRANSFORMER I and the Mobile Power Plant that were driven from Detroit to Washington, D. C. for just this occasion. They are parked outside this building.

Winning vehicle in the all-electric class was an Electric Fuel Propulsion sedan (left) driven by Cornell students. Runner-up, also an EFP van, was driven by students from Stevens Tech. Only problem with the sedan was a burnt-out motor, the van ran without major incident

Detroit dominates Clean Air Car Race

Only two of the six pure-electric cars entered in the Clean Air Car Race completed the 3600-mile cross-country run from Boston, Mass., to Pasadena, Calif. According to sources close to the race, however, the electric cars not only performed better than expected, but they performed better than in the 1968 "Great Electric Car Race."

While the electric cars did not fare as well on the basis of time (about 2 days behind) or point score (less than half), when compared to internal-combustion-engine (ICE) cars, the race is considered to have made positive contributions to their development. It reinforced the idea that electric cars that can go cross-country can perform satisfactorily in the less-rigorous city driving for which they are designed. student interest and enthusiasm has stimulated corporate activity; and techniques that would not have been looked into otherwise have been evaluated or tested

Some 43 cars started out in the seven-day cross-country race. Of these, 36 were "scored" by the race committee. The dropouts were in the electric, hybrid, steam-turbine, and gas-turbine categories. Most of the cars were powered by modified internal-combustion engines.

Overall winner was a Ford Capri modified by Wayne State University students to run on unleaded gasoline. It was also equipped with exotic catalysts and other experimental systems to control emissions.

By and large, as the entrants began crossing the finish line on August 30, the electric cars were conspicuously out of sight. "The electrics," remarked one of the race coordinators at the finish line, "were just not designed to travel the distance at the pace we set."

The Cornell team commented that their car "runs very well. But it is primarily designed for short hauls. It can go longer distances, that we proved. But at present, it really hasn't been designed for that type of driving." And a race participant from the University of Michigan called the electrics the "right cars in the wrong race."

The two electric vehicles completing the race were both manufactured by Electric Fuel Propulsion Inc, Detroit The winning electric vehicle, even though it came in second, timewise, was a 1970 sedan driven by Cornell University students. The first electric vehicle to cross the finish line was a converted Swedish mail truck driven by students from Stevens Institute of Technology Because of the scoring system used, it was placed second.

The van, sponsored by American Smelting & Refining Co, made the trek across country without any unusual problems. About halfway through the race, it was still some 100 miles behind the Cornell car, but jumped ahead when the sedan broke down Electric supply from its lead acid batteries was 120 vdc driving a 15 hp dc motor

The winning Cornell EFP sedan performed "well" over most of the route. It took about 33 hours to complete the first leg to Toronto, due mainly to the time required to recharge the 26 6-v tripolar batteries.

Between MIT and Champaign, Ill. the Cornell car had no breakdowns or major problems. "Somewhere in Texas, part of the motor burnt out because we were driving it too hard," commented one of the student drivers.

The car was able to continue, but broke down just outside of San Diego. Team members spent about two hours trying to repair the motor, but finally, exhausted and already two days behind, gave up. The car was towed the last 120 miles to CalTech.

Observers expected one of the big tests for the electrics would be their performance through the hot desert areas of the Southwest, but the Cornell team reported no overheating problems. Carl Swartz, a contestant in the 1968 race and an observer for EFP, commented that the lead-cobalt batteries used in the Cornell car "are much superior to anything we used then. . . . We had to [put dry ice on them] in 1968."

Other electric cars in the race, which did not make it across the finish line, included cars driven by students from Georgia Tech, Boston University, Oakland University, and Iona College.

The Georgia Tech car was a modified 1970 VW fastback sedan powered by 24 6-v Prestolite batteries and a 25-hp dc series motor. A chase truck carrying a diesel engine-generator was to keep the batteries charged In operation, 8 of the car's 24 battery packs were to be changed at a time.

Although the car was running well, between Toronto and Detroit it encountered trouble with a circuit breaker on the generator used to charge the batteries and lost two days. Since the car was not using the charging stations along the route, loss of its support vehicle was critical.

The Boston U car, sponsored by Anderson Products and Avis, had much the same problem with its charger in a support truck. The Boston U car, however, used a different approach in handling its batteries, which were stored on a removable "tray" fitted lengthwise into the center of the car. This tray was to be removed and recharged on the support truck. After leaving Ann Arbor, the team started using the charging stations along the way. But trouble developed in the car's drivetrain about halfway cross-country, and it was towed to the Pasadena finish line.

The Oakland University car broke down about 50 or 60 miles outside of Ann Arbor due to burnt-out diodes. In addition, it had suspension problems. The car, a 1962 Nova, was carrying about 3,000 lb of extra weight in batteries without modification of its suspension system.

The Iona College team, driving a 1962 VW, had promises that dealers along the way would swap used batteries for new ones. According to reports from Oklahoma City, the car got about 20 miles west of St. Louis when it ran into "administrative problems." One of the race coordinators said the student drivers refused to accept one of the race judges.

Although the pure electrics were slow, the electric hybrids were not. They had their mechanical problems, but for the most part performed reasonably well. This was because they relied on conventional power systems for the most part. In the final scoring, however, they were among the vehicles with lowest overall scores.

While the 1968 event had some elements of a light-hearted, fun-loving challenge by college students driving "electrics," the similarity ends there The 1970 version was a well-organized venture dominated by modified ICE cars

Industry contributed support for the race and backing for almost all the cars. Auto manufacturers were particularly generous. They supplied cars, engineering knowledge, parts, and expense money. Though other companies were not so "visible," their impact was felt. Boston Edison Co, for example, contributed $3,000 to the race committee and a Massachusetts gas company sent a truck to refuel liquid-natural-gas cars in the race.

Electric utilities along the race route set up almost 70 charging stations. The stations ranged from 14 to 79 miles apart, depending on terrain and availability of a suitable recharge location.

At each location, a utility spent $430 for each station. This does not count the cost of installation or any line or service extensions necessary. Conservative estimates place the total utility investment in the race at over $40,000.

Each recharge station consisted of a large (about 5 x 3 x 3-ft) fiberglass enclosure manufactured by EFP, containing a Westinghouse breaker, cables supplied by the Copper Development Assn, Pyle-National connectors, and a utility-supplied meter. The equipment used was donated, or supplied at or below cost, by the various companies involved. Had the parts been purchased "on the open market," the equipment cost would have been at least double.

Because of the route followed, some utilities had multiple stations in their service areas. These included Niagara Mohawk (6), Ontario Hydro (6), Public Service of Colorado (4), Southwestern Public Service (5), El Paso Electric (4), and San Diego Gas & Electric (4).

Emissions from the cars entered in the race had to meet or exceed the 1975 federal air-pollution standards. These figures, expressed in grams per mile per vehicle, are: particulates, 0.1; oxides of nitrogen, 0.9; hydrocarbons, 0.5; and carbon monoxide, 11. According to the race committee, the electric cars' emissions were based on the "equivalent power plant emission per 0.5 kwhr—which closely approximates the 1975 standards."

Concern about world problems of pollution and noise, particularly those caused by ICE cars, has contributed to studies under way towards the formation of a European Pool of manufacturers of electric and electronic cars headed by La Voiture Electronique, Paris, France. The pool, as presently envisioned, would promote battery-electric vehicles in Europe, and would collaborate on an international basis with other interested organizations throughout the world.

La Voiture Electronique reportedly brings to the proposed pool brushless motors with electronic commutation and electronic controls. It is described as a variable-reluctance motor having a wound stator and solid or plate-shaped rotor. These motors appear to be similar to those developed by General Motors for the US Army Tank Automotive Command, and to a thyristomotor used about two years ago by Tokyo Shibaura Electric Co in an experimental electric vehicle.

La Voiture Electronique's motors will be used in a small, short-range commercial vehicle ($900) intended for factory and other off-street applications. The electronic control of the vehicle will be similar to an airplane pilot's "stick." It is expected to be introduced in October or November.

A second European firm, Enfield Automotive, of Great Britain, which last November did not expect to put an electric vehicle on the market for about two years, now is talking in terms of introducing in the very near future a car called the Reve—an improved version of the Enfield 465 introduced at the Electric Vehicle Symposium in Phoenix last year, and an 8000-series car developed since then. ■

Electric heating installations rise, but cooling grows faster

Electric heat was installed in 25% of all new one-family homes in 1969. This is up from 22% in 1968, according to the Department of Commerce and the Department of Housing & Urban Development.

Central air conditioning continued its gain in acceptance in new one-family homes by jumping five percentage points between 1968 and 1969 to 36%. In 1966 it was 25%. In this market, utilities face a "reverse builder gap," the Electric Heating Assn said, because builders are installing central air conditioning at a greater rate than consumers who build their own homes. In 1969, builders installed air conditioning in 39% of the homes they built, compared to 32% in owner-built homes (see box on next page).

While the data published by the government shows that, nationally, builders constructed 60% of the single-family homes in each of the past three years, it also indicates a changing regional pattern. Builder-built homes between 1966 and 1969 declined in the Northeast (64% to 56%), remained constant in the North Central region (58% to 59%), and increased in the South (49% to 54%) and West (71% to 79%).

During this period, electric heat installed in all single-family homes rose from 20% in 1966 and 1967 to 22% in 1968 and 25% in 1969. Concurrently, electric heat installations in builder-built homes rose from 13% in 1966 to 14%, 16%, and 20% in the succeeding years. Electric heat in owner-built homes rose from 27% to 33% during the same period.

On a national basis, the government figures show gas heat to be holding its own at 64% of all new one-family homes, while oil continues its drop-off, from 13% in 1966 to 9% in 1969.

According to EHA, the builder gap still exists for electric heat, though it is

Utility vps watt rod it to Arizona

Arizona Public Service's electric car zips into Phoenix after crossing the country. Car, a Mars II, received "tremendous reaction" from public

You've heard the story:

About the electric car that has that extension cord [illegible] Goes like mad until it [illegible] its electric [illegible]

Big joke.

Arizona Public Service heard the story, too, and today they are really laughing. Because October 6, APS finished driving an electric car—a Mars II—2,000 miles cross-country. And without an extension cord.

The 2,000 mile jaunt began in Detroit Sept 20, after APS purchased the second production model 1967 Mars II (first production Mars II was sold to [illegible] P&L).

Developed by Electric Fuel Propulsion Inc, Ferndale, Mich., the Mars II (a modified Renault R-10) is the brain child of Robert Aronson, president of EFP, and Donald Swanson, a Ferndale Renault dealer and vice president of EFP.

Motorists wouldn't bat an eye at the utility's new car—unless they noticed a missing exhaust system, an absolute lack of engine noise, or the fact that the car had been trusted to the man who runs the substation.

By the time Mars II reached Phoenix, its final destination, it had passed through nine states, and made 36 planned stops about every 60 miles to recharge the car's 20 six-volt, lead-cobalt batteries.

"Refueling" was carried out at utility substations and garages and at restaurants along the route—preselected spots where APS drivers could plug their Mars watt-rod into a 240-w, 3-phase system. Jubilant APS personnel say that throughout the trip the car had received "tremendous reaction" from the public.

The drivers included, at various stages: Vice Presidents M. C. Titus, research & development, and Don Willis, marketing; Ted Dando, APS publicity manager; Bob Jones, project engineer; Paul Escen, APS photographer; and Robert Aronson, EFP's president. They reported that at normal cruising speeds of 45 to 55 mph, the car "worked perfectly." In St. Louis, however, the car was delayed a day due to mechanical, not electrical failure. The blame was put on a coupling that joins the motor to the drive shaft. It was quickly replaced.

Between a beefed-up suspension system and 1,700 lbs of batteries, the weight of a Mars II is 3,640 lbs compared to the usual R-10's 1,950 lbs. The car features a regenerative braking system that provides dynamic braking as it automatically recharges the batteries at currents that range from 165 amps at 60 mph to 30 amps at 10 mph. In addition, the APS electric carries a 12-v auxiliary battery that powers the magnetic control panel, lights, radio, and horn.

The differences between Mars II and the electrics of 50 years ago are great. Early electrics used conventional lead-acid batteries and, because the cars were slow and had extremely short ranges, they were strictly for in-town use (Grandma's Baker never made a 2,000-mile trip). On the other hand, Mars II, powered by a 15-hp direct current motor, can accelerate from 0 to 40 mph in ten seconds, can hit a top speed of 60 mph, and will run from 70 to 120 miles before the lead-cobalt batteries must be recharged.

Aronson claims that the batteries in his cars can be recharged 800 times, which would be equivalent to driving from between 56,000 to 90,000 miles. The batteries will accept a high recharge rate without damage to the cells. An 80% recharge on a completely discharged battery can be attained in 30 minutes, a 100% recharge in 90 minutes.

Once in Phoenix, the Mars II, which was named by Aronson's 9-year-old son Douglas will be the center of an intensive promotion and publicity campaign to get the public interested in electric cars.

"We have purchased this car and have made the trip to stimulate public interest in the vehicle and at the same time give APS people first-hand experience with electric transportation vehicles," said Walter Lucking, Arizona Public Service chairman and chief executive officer.

electric fuel propulsion corp.

1976 TRANSFORMER I Electric Car

DESCRIPTION. 2-Door Coupe, 4-Passenger, International Size, Electrically Powered, with a wide range of luxury equipment available such as automatic transmission, power steering, power brakes, power windows, tilting steering wheel, swivel bucket seats, electrically powered Sky Roof, power door locks, six-way power seat, tinted glass, AM/FM Stereo radio and tape system and many more.

RECOMMENDED USES. For Professional and Business people in towns, cities or large metropolitan areas who drive 60 miles a day or less (20,000 miles a year or less) in any climate and who would be able to charge the car when not in use by plugging into a 110-volt or 220-volt receptacle at home or office.

PERFORMANCE (on level roads with batteries 50% or more charged).

Top Speed (for passing): 60 mph

Cruising Speed on Expressways: 50 mph

Acceleration: 0 to 30 mph in 12 seconds

RANGE (with fully charged batteries at 80°F or warmer).

On Cross Country Trips: 1,100 miles per 24-hour day with Mobile Power Plant in tow (22 hours at 50 mph with 2 hours for refueling and resting).

Commuting between Suburbs and City: 50 to 75 miles with 80% driving on open Expressways, 20% driving in city traffic and with some supplemental charge while car is parked and not in use (assuming maximum one-way trip to be 37-miles).

RECHARGING TIME.

Using an External Fast Charger: 45 to 60 minutes for an 80% charge depending on the initial rate of charge from power source. EFP gasoline fueled Mobile Power Plants or electrically powered Charge Stations which would normally be located at gas stations or shopping centers would be considered as External Fast Chargers. A 10-minute charge would result in 15 miles of added driving range; a 30-minute charge would give 30 to 45 miles of added driving range.

Using the Car's On-Board Slow Charger: Approximately 8 hours when plugging into a 220-volt, 50 amp. circuit at home or office, assuming the battery is fully discharged; or approximately 48 hours, if the battery is fully discharged, when plugging into a 110-volt, 15 amp. circuit.

1976 TRANSFORMER I Electric Car

PHYSICAL SPECIFICATIONS.

Dimensions in Inches:

Wheelbase	112.0
Length	212.3
Width	76.6
Front Tread	61.5
Rear Tread	60.7

Exterior and Interior:

All-Welded body on perimeter frame
Deep-Dip Rust-Proofing
Molded full foam seating, front and rear
Armrests, front and rear
Cut-pile nylon carpeting
Soft-rim steering wheel

Mechanical:

Full Coil suspension system
Front disc brakes
Rear drum brakes
Front and rear ride stabilizer bars
Dual cylinder, 4-wheel hydraulic brakes

Cooling and Defrosting:

Flow-through Power Ventilation
Liquid fuel heater and defroster

Seating:

Front -- Swivel Bucket or Bench Seat
Rear -- Bench Seat

Motor:

32 H.P. Direct Current

Propulsion Battery:

180-volt Tri-Polar, Lead-Cobalt Power Unit

Controller:

Solid State Electronic Control

Tires:

H78-15 Bias Belted Ply Blackwall

Charger:

On-Board Slow Charger, dual voltage: 220 VAC 50 amp or 110 VAC 15 amp input

electric fuel propulsion corp.

EFP MOBILE POWER PLANT
(45-Minute Battery Charger)
Model M-375-KVA

DESCRIPTION. Self Contained, Trailer Mounted, 37-1/2 KVA Gasoline Engine Generator.

USES.

1. For fast charging electric cars (equipped with Tri-Polar, Lead-Cobalt Fast Charge Batteries) at a fixed location where both car and Power Plant are parked and not in motion--for example, at a gas station.
2. For fast charging electric cars under mobile conditions where both car and Power Plant are traveling on a highway.
3. For providing emergency lighting and power for homes, gas stations, hotels, hospitals, office buildings, refrigeration warehouses, etc. in case of electrical "blackouts" or "brownouts".
4. For providing a multitude of other electrical services where a.c. or d.c. current are used for such tasks as welding, operating electric tools, etc.

SPECIFICATIONS.

Overall Dimensions on 2-Wheel Trailer: 100-inches long x 67-inches wide x 47-inches high

Trailer Frame: Welded Aluminum

Track: 57-inches

Net Weight with full tank of gas (21 gallons): 1860-pounds

Wheels and Tires: 13-inch wheels; 6.50-13 Trailer Duty Tires

Brakes: Hydraulic, electrically operated

Trailer Lights: Tail, turn indicator, stop and side clearance lights

Engine: General Motors 250-cubic inch, 1 barrel, 6-cylinder, 105 horsepower, with 21-gallon gas tank, High Energy Ignition (no breaker points or ignition condenser), catalytic converter, designed to run on no-lead gasoline.

Generator: 37-1/2 KVA, 4-Pole, Brushless, Class F Insulation, 1800 RPM, Aluminum Frame.

Page 1 - May 14, 1975 - Specifications subject to change without notice.

robbins executive park east • 2237 elliott avenue • troy (greater detroit) mich. 48084
phone 313/588-0250 cable: elefuel, detroit

EFP MOBILE POWER PLANT
Model M-375-KVA

SPECIFICATIONS. (continued)

Electrical Characteristics:

A.C.--37-1/2 KVA Continuous Duty (30 KW at 0.8 Power Factor)
60 Hertz (50 Hertz available as an option)
120/208 Volts, 3-phase, "Y" connected
Solid State Voltage Regulator, adjustable plus or minus 10%

D.C.--35 KW Continuous Duty

Battery Charging Capacity--	144-volt Battery	180-volt Battery
Maximum Charging Voltage	180-volts	220-volts
Maximum Charging Current	250-amps	200-amps

Instrumentation:

- AC Voltmeter
- AC Ammeter
- DC Voltmeter
- DC Ammeter
- Engine Hour Meter

Controls:

- Master Key Switch
- Mode Switch for automatic or manual control
- Start Button
- Stop Button
- Voltage Adjust

Indicating Lights:

Ignition-On (engine running)--Green
Engine Fault--Red
Battery Discharge (12-volt starter battery not charging)--Amber
Low Fuel Warning--Flashing Amber

Engine Electronics Package:

- Starter Cutout Speed Switch (disengages starter upon starting and Engine Hour Meter)
- Start-Abort Timer (locks out starter after failure to start in 10-seconds)
- Startup Fault Delay Timer (arms oil pressure switch after 5-seconds)
- Automatic Fault Shutdowns--Red Light--
  - Low Oil Pressure
  - Manifold Overtemperature
  - Water Overtemperature
  - Overspeed
  - Engine Alarm contacts (10-amps, 12-volts)
- Remote controlled automatic starting--2-wire

electric fuel propulsion corp.

1976 TABOO II Electric Go Cart

DESCRIPTION. Single passenger, Electrically Powered Go Cart manufactured from heavy wall steel tubing, all welded with Contoured Bucket Seat.

RECOMMENDED USES. For children and adults on large, paved areas (off the street), Go Cart Tracks, side walks (where permitted) for racing, maneuvering and just plain fun.

PERFORMANCE. (on level, paved area with batteries 50% or more charged).

Top Speed in First Speed Range: 8 mph

Second Speed Range: 15 mph

CRUISING TIME. 2 to 4 hours

RECHARGING TIME. 6 hours at 20 amps. if fully discharged.

PHYSICAL SPECIFICATIONS.

Dimensions in Inches:		
	Length	60
	Width	34
	Height	25

Exterior:

All-Welded Racing Frame
Molded Contoured Bucket Seat
Dual-grip Racing Steering Wheel

Mechanical:

Quick ratio steering
Mechanical brakes on both rear wheels

Motor:

Series wound 1/4 horsepower

Propulsion Battery:

24-volts, 70 ampere hours

Controller:

Series-Parallel Contactor Type with two-speed control and on-off switch and key.

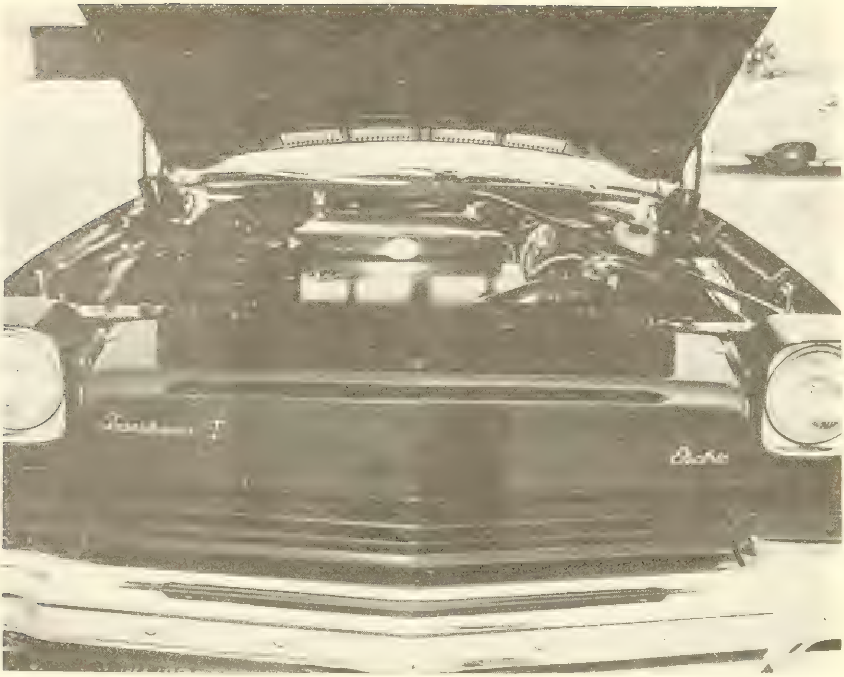
SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE - May 14, 1975

366 west eight mile road • detroit, michigan 48220 • phone 313 545-2224 • cable: elefuel, detroit

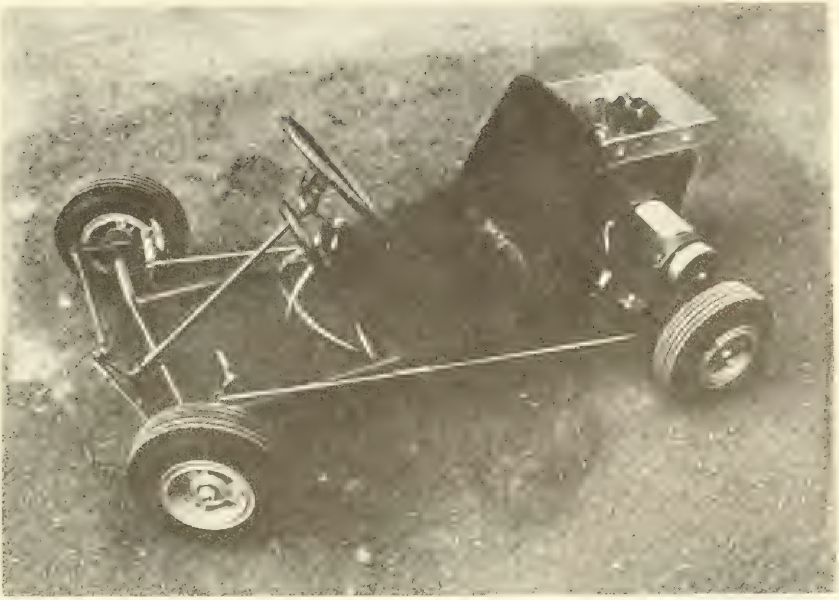
EFP 1976 TRANSFORMER I INTRODUCTION

Electric Luxury: "Transformer I," the first electric car to be available with the accessories of a luxury automobile, made Detroit's first debut for the Bicentennial Model Year of 1976. Designer/Manufacturer Robert Aronson said, "The move from experimental to production passenger car was made possible by a series of innovations in battery technology."

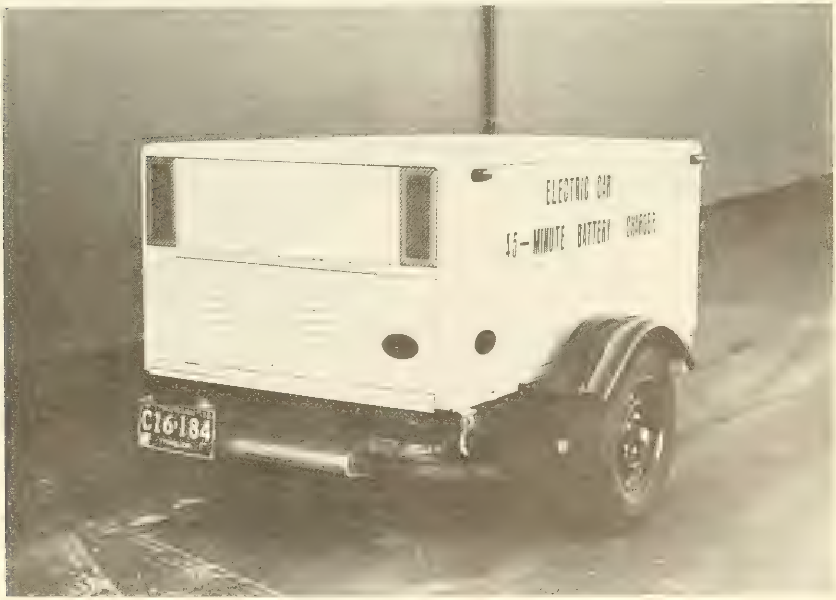
"International" Styling, Markets: The powerful 180-volt Lead-Cobalt battery has enough output to allow comfortable, stable cruising at 50 mph, with passing speeds up to 60. Well-wishers from Asian, African and European markets attended the showing of the Transformer I today. The four-passenger two-door coupe has a 112-inch wheelbase and an overall length of 212.3 inches, and is in the International Style Class.



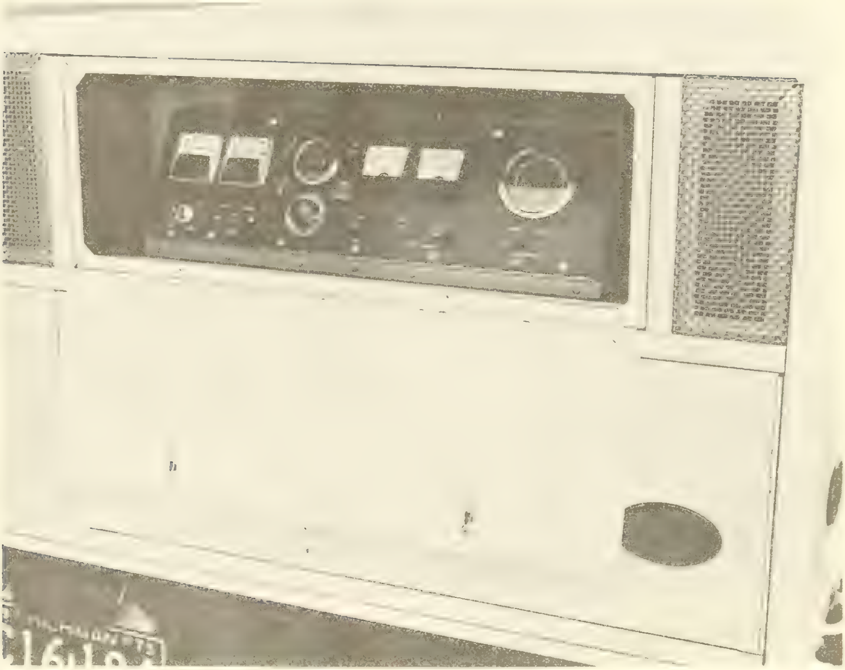
Sleek, Purring Boxes: Under the hood of the brand-new Transformer I, the 32-hp powerplant puts out a stable 1800 rpm at cruising speed, through an automatic transmisison. All components of the car are products of Detroit, assembled at the manufacturing facilities of Creative Industries of Detroit.



Powerful Little Brother: The "Taboo II Go-Cart", designed and introduced to the press by Doug Aronson, the son of the designer of the Transformer I, uses a quarter-horsepower motor with an output of 1800 rpm. It is the first all-electric go-cart, and will retail for $495 from Electric Fuel Propulsion dealers.



Rolling Fuel Station: The 375 KVA Mobile Power Plant introduced here today can throw a quick recharge into new state-of-the-art Lead-Cobalt battreies in a scant 45 minutes. In addition, the unit can be used for emergency or special purpose power requirements. One possibility is to hook the 375 KVA to a Transformer I, for a constant recharge in motion.



Mr. ARONSON. I have a question at the outset. I have just been handed apparently what is a new version of H.R. 5470, which is called H.R. 6198. I'm wondering if these are one and the same.

Mr. McCORMACK. Does that have my name on the front of it, Mr. Aronson?

Mr. ARONSON. Yes.

Mr. McCORMACK. Yes. It's an identical bill. We have submitted several of them because no more than 25 sponsors are permitted on one bill.

Mr. ARONSON. I see. All right.

In reference to my written testimony, I would like to call your attention to a correction. On the title page it says, "June 4." It should be June 5. The reason for this is that this was done about a week ago, and I thought that I was going to be appearing on June 4.

I would also like to call your attention to the very last page of this testimony, page 9. At page 9 I stated—and remember, this was written over a week ago—that we would be driving our electric cars from Detroit to Washington. That was a prediction, and we did it. We left Sunday afternoon from Detroit, and we drove in as far as Breezewood, Pa., on the Pennsylvania Turnpike, stayed overnight Sunday night, and drove into Washington Monday.

With me is John Trepcyzinski, who is our mechanical engineer; and Dick McLean of Wolverine Diesel Co. in Traverse City, Mich. Dick McLean was involved in the construction of the mobile powerplant, or the battery charger, that was on a two-wheel trailer which accompanied us on the trip, and which actually was hitched up to the electric car, and which enabled us to drive straight through.

We stopped, as I mentioned, at the Holiday Inn; drove in normally, just as one would drive in any car. Now, the reason we did this was to demonstrate—and, of course, this bill talks about demonstration—that an electric car can be driven long distances.

We've done this on many occasions. The first occasion was in 1967, when Senators Muskie and Magnuson had a similar bill, or a bill that would have provided R. & D. money for developers, and at that time we drove in another car. It was a smaller car, but nevertheless it was driven all the way from Detroit here, and we tried to demonstrate at that time that there was sufficient technology to enable an electric car to be built and driven at highway speeds, over mountains and over all sorts of terrain, just like any other car, and that such a vehicle at that time, in 1967, could have been produced, could have been mass produced.

Now we're some years later and we're still trying to tell the same story.

In 1967, I listened to testimony that was very similar, was almost a carbon copy of what I've been hearing here, people saying, "Let's delay things. Let's slow things down. Let's make this an R. & D. project. Let's not go too fast. Let's wait for the next battery."

I remember at that time there was a lot of talk about the zinc-air battery and some other batteries, and they were just 1 or 2 years off, or 2 or 3 years off. "Let's wait for them. Let's not move too fast."

Well, here we are what? Some 7 or 8 years later, and we're still waiting for those things.

I think we've waited long enough. I think now is the time to move ahead with what we have with existing technology. We've demonstrated here, and other developers who have been present here have demonstrated, that electric cars are a reality. They're not only a reality in this country, but they're a reality in many other countries, such as England, and now Japan. We've demonstrated in our case that electric cars can travel, well, in the case of the Clean Air Race in 1970, at 85 miles an hour, not 20 or 30 miles an hour, now.

Now we have other types of electric cars that are for different purposes, and they are valid types of vehicles for other applications, but a lot of people say, "Gee, electric cars have so many limitations. They can't do this; and they can't do that."

Well, in 1970—that was several years ago—we drove two electric cars in the Clean Air Car Race from the campus at MIT at Cambridge, Mass., to Cal Tech in Pasadena, Calif., in 8 days, and one of those cars, according to the report of the observers who were following the cars, had a top speed on level ground of 85 miles an hour, and the other 65.

Now, these things can be done. The technology, I think, is a lot farther along than most people realize. Why haven't we gone into production then? Well, it's very simple. We haven't had the financing to do it. It takes a lot of money to go into production of electric cars. It takes some stimulus. It takes some shot in the arm, perhaps a subsidy. It takes something, as Bob Beaumont pointed out this morning, to install the confidence required necessary in stockholders, and so on. It takes a priming of the pump to get these things started.

Why did the Government of Japan, the MITI, put up $13½ million, and then that was raised to $17 million, and I don't know what it is now, to get an electric car developed and going? Why did they do that? It's a priming of the pump that's required, and that's what this would do. That's what could have happened in 1967, but it was shot down.

I heard a lot of testimony to the effect that industry should do its own R. & D.; we don't need Government help. Well, that industry that claimed it was going to do all those things hasn't done it, as far as electric cars are concerned.

I'll tell you just a little bit about our car. Incidentally, the car is outside in the Horseshoe, right out front here, and the Mobile Fast Charger is there too, if you'd like to look at it.

Mr. McCormack. If I had a chance, I would like to go down and visit after the hearing is over, Mr. Aronson.

Mr. Aronson. Right.

This car is a full-size vehicle. It has a lot of the safety features on it that we've come to expect in large size vehicles, such as power steering, power brakes, automatic transmission. This particular one has power windows as well, and it's available with all the features that you normally would buy in a full-size car, that you normally would consider in a full-size car.

The reason we've done this, that we've equipped the car this way, is, again, to demonstrate that electric cars can have all of these features that we've become accustomed to.

We've also developed a battery-powered air-conditioner for this car, and we expect to be able to retrofit our initial production cars with air conditioners within the next year.

Mr. McCormack. How many kilowatt hours does the air-conditioner require?

Mr. Aronson. In the case of this particular car, our air-conditioner would require a quarter horsepower.

Mr. McCormack. And with a gasoline motor?

Mr. Aronson. With a gasoline motor in a car of the same size, it generally takes about 4 horsepower. Now, the reason for that is that the gasoline-powered air conditioner operates—or the compressor operates—on a pulley which is connected to the engine. When the engine is idling at, let's say, 800 rpm, that air conditioner must be fully efficient at that point, at that low speed. When the engine is running at 3,000 or 4,000 rpm. the air-conditioner is way beyond its capacity; it's doing a lot more than it requires. With the electrically powered air conditioner, we're using an electric motor which runs at a constant speed all the time, regardless of whether the car is stopped or going, and so we can optimize the air-conditioning. Second, we have found a way to separate the Freon from the oil, so we're pumping through Freon in the system rather than Freon and oil, and we found that when you contaminate oil with Freon, it takes a lot more power to get the same cooling.

So, at any rate, an electric car has been produced. It has all these available options that you would find on any car, except air conditioning, and air conditioning will soon be available. So there you've got everything.

As far as the top speed, 85 miles an hour. Now, we've set this at 60 miles an hour, 60 to 65, because of the speed limit and because this gives us a greater range. The range is 50 to 100 miles, depending on—of course, you're familiar with all the variables per charge—and the special lead cobalt batteries can be recharged to 80 percent of capacity in 45 minutes. This is how we are able to win these cross-country races, and travel 400, 500, 600 miles a day, by rapidly charging these batteries. The batteries do not suffer because of this. They are designed that way, designed to be rapidly charged, to be operated at high charge and discharge currents.

So much for the car, except to say that we plan to be in production next month, starting with one car a week, and we hope that by the end of the year we'll be up to 25 cars a day. We have that capacity.

During the course of next year, if all goes well and the good Lord smiles on us, we'll make something like 2,500 cars, and we'd like to offer a thousand of those to you folks under this bill.

Next week at Cobo Hall at the Automotive Electronics Conference the cars will be shown to the public for the first time and to dealers. That's during the 10th, 11th, and 12th, and we'll announce the price at that time. This is an expensive car, and it's in the price range of a Cadillac or a Mercedes-Benz. Of course, cost of production is related to volume. Our volume naturally is very, very limited now, one car per week. When that volume gets up to 25 cars a day or more, obviously it will be possible to lower that price.

Now getting to this bill, I have a couple of questions and comments.

First of all, could I ask, in reference to section 7, Demonstration, the term "significant numbers," which is, I guess, defined on page 5 as 5,000 or more. Now, there's a question in my mind if in section 7 any individual contract would be let for 5,000 vehicles or more.

Mr. McCormack. No. I'm sure we will have either in the bill or in the report some provision that provides a maximum and a minimum of vehicles that can be purchased from any one vendor.

I do not presume to be wise enough to make any decision on that point at this time, but I might pull some numbers out of the hat, that I would expect that the maximum would be perhaps 500 to 1,000, and maybe the minimum would be from 100 to 500. So I think we've in the range of having from 10 to 25 vendors involved.

Mr. Aronson. Perhaps the language confused me a little bit. It wasn't real clear, but now I understand.

Mr. McCormack. Of course, we will feel quite free to rewrite the bill in a new, clean form, and take advantage of all the suggestions we have had in the hearing, and this is very likely to be one of those. The words "significant numbers" are sort of a jargon around here, and we don't have to follow it unless we choose to.

Mr. Aronson. Fine. Thank you for clearing that up.

In the same section, section 7(b), I would like to comment on what I read here: "development of performance standards and criteria." I would like to suggest—and perhaps this is already comprehended in the bill—that several types of vehicles be considered. As you have seen here, there are many types of vehicles, from very small vehicles to very large vehicles, buses and so on, and I would hope that it is your intention to define several different types, perhaps five or six types, which was suggested earlier here, rather than to zero in on one particular type.

I think that the developers represented here have kind of specialized and put all of their energies in the development of certain types of vehicles, and they could produce those types much easier than if they were compelled to produce something that they hadn't really be developing.

Mr. McCormack. Yes, again, I think we are in complete agreement on that matter, and clearly the legislation would contemplate, and the report would contemplate, having various types of vehicles, within reasonable limits.

Mr. Aronson. Wonderful.

Now with reference to section 8 on page 10, there are three words that kind of scare me. In line 17 it says: "For competitive procurement purposes . . ." I am really afraid of that. When I hear "competitive procurement purposes," I really don't know what that means here, but I do know this: that if competitive bidding is the end result of this bill the chances for small business firms, such as ourselves, I think, will be greatly diminished.

I would like to suggest that rather than competitive bidding—and you know we're not talking about well-defined things like apples and bananas. We're talking about things that really have no definition, things that have just been created, types of vehicles that have never existed before—rather than competitive bidding, I would suggest negotiated bidding—not bidding, but negotiated, the contracts being negotiated for certain types of vehicles, or even that consideration be given to purchasing on a cost-plus basis.

I know that in the case of our company, I'm sure our stockholders would be willing to take over the cost and put it right back into R. &

D., and, of course, as I see it, and as our company sees it, the best way to promote R. & D. is to have viable companies that are making products that are salable at a profit, and to have this profit then regenerated, or put back into the R. & D. budget.

R. & D. by itself is great, but stockholders are looking eventually for profits and dividends, and if everything is R. & D. and there is no prospect of profits or dividends, why then the incentive is gone.

So if we had a situation where we could negotiate the price for a given type of vehicle, and that price would give us a decent profit, a minimum return, it would be healthy for us developers, and our stockholders would like it, and I'm sure that it would make possible the continued development of our R. & D. activities.

So, really, competitive bidding scares me.

You recently had an example of competitive bidding with the Post Office procurement of 350 vehicles. Our company didn't bid on that. I predicted the outcome. I didn't even bother to bid. We're too small to bid against large companies. Large companies can do things that we can't do.

Section 10, page 12, refers to small business. I have a couple of questions there.

First of all, what is the definition of a small business? I've seen, I think, where the SBA defines a small business, or used to, as a company with 1,000 employees. And I would ask the question: If the company had a thousand or 900 employees and if that company were a wholly-owned subsidiary of another company that had 3,000 or 4,000 employees, would that company be a small business? And then what would our chances, as a very small company, be to compete with that entity?

This "small business" really worries me, unless that is defined.

Second, what percentage of the lease funds would go to so-called small business? Would it be 5 percent, 10 percent 20 percent? What chance do we have as a small businessman? We don't have 1,000 employees. None of us developers, I don't think, with the possible exception of one, has a thousand employees. What chances do we have to get a real crack at this thing?

So those are some of the questions that I had.

I would say, in summary, that our company, and I personally, support your bill, and what you're doing, and what you're trying to do, and we'll do everything that we can to make it a success.

Mr. McCormack. Thank you, Mr. Aronson.

With respect to the last two points you raise on competitive procurement purposes and competitive bidding and also the definition of small business, I am sure we very much appreciate that testimony and the comments, and the committee is going to be searching and looking at these things. It is too early for me to try to make any definitive statements in these areas, but clearly you have raised points that I think are very well taken, and we are going to be looking at them seriously as we go along.

Mr. Aronson. Thank you.

Mr. McCormack. Thank you.

Mr. Ottinger, do you have a question?

Mr. Ottinger. No. I would just like to thank the witness for a very fine statement, and to say that I think we will address ourselves to the problems of the small business participation in this program. It is one of the things that a number of us are very concerned about.

We appreciate your testimony.

Mr. McCormack. Mr. Brown.

Mr. Brown. No questions. Thank you. And thank you, Mr. Aronson. I would like, if we have a chance at 3 o'clock, to go down and take a look at your car, if it will be here.

Mr. Aronson. Thank you very much for the opportunity.

Mr. McCormack. Thank you very much, sir.

Our next witness is Mr. Domenic Borello, president of Die Mesh Corp. of Pelham, N.Y., and I would like to ask Mr. Ottinger to introduce him.

Mr. Ottinger. Thank you, Mr. Chairman.

Die Mesh Corp. operates within my congressional district. They have done a good deal of pioneering work on the electric car, and have done it all with a considerable amount of their own money, to the point where they have put something of a burden on their other business activities.

They are prepared to go ahead, but they need help, as Mr. Aronson indicated with his small company as well, in order to be able to move further forward in this field.

We are very proud to have Die Mesh in our congressional district, and look forward to having them operate a major electric car facility within that area some day within the near future.

It is very nice to have you with us, Mr. Borello.

STATEMENT OF DOMENIC BORELLO, PRESIDENT, DIE MESH CORP., ACCOMPANIED BY DANTE J. ALBERI, VICE PRESIDENT, DIE MESH CORP.

Mr. Borello. Thank you very much, Mr. Ottinger, and Chairman McCormack.

Mr. McCormack. May I ask you how many people you have working for Die Mesh?

Mr. Borello. About 15 to 20.

Mr. McCormack. May I ask you, Mr. Aronson, how many people do you have working for your company, sir?

Mr. Aronson. We have about a dozen now, directly, and about 30 or 40 indirectly through subcontractors.

Mr. McCormack. Thank you very much.

Mr. Borello, please proceed. Would you care to insert your statement in the record?

Mr. Borello. I would like to read it first, and then have it in as a statement.

Mr. McCormack. Very fine.

[The complete prepared statement of Mr. Borello, together with informational material submitted is as follows:]

DIE MESH CORP. PRECISION EXPANDED METALS
629 FIFTH AVENUE, BOX 362, PELHAM, NEW YORK 10803
Tel. 914 738-5444

At the outset I would like to thank this committee for giving the Die Mesh Corp. the opportunity to testify, concerning various aspects of the "Electric Vehicle Research Development & Demonstration Act of 1975." We feel that our on the road experience with our own Electric Vehicle over the past-6-years can contribute to the understanding and implementation of this bill.

For the past-6-years the Die Mesh Corp. has committed itself to placing an Electric Vehicle of its own design on the road. We have attempted to demonstrate to the consumer, not only the feasability of an Electric Vehicle but also its safety and low maintenance characteristics through exhibiting our vehicles in both exhibitions and on the road use. If the Die Mesh Corp. throughout this period had sufficient financing to mass produce these Electric Vehicles, our commitment would now be a reality and this bill would not now be necessary. However, all our efforts to raise capital for the mass production of Electric Vehicles have been unsuccessful. Neither the private financial world nor any of our governmental agencies have been willing to finance a venture such as this in a meaningful way. In relation to the oil crisis, American money has been used to solve emergency problems for foreign countries, helping to place our country in a deficit position and weaken our economic stability.

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Our nation is now in a two-fold crisis; first, the people of our cities are being choked by fossil-fuel pollutants and secondly, the average U.S. citizen is on the verge of being priced right out of the gasoline market with the next increase in the cost of gasoline. We feel the mass production of Electric Vehicles can provide short term relief and a long term permanent solution to these problems. The energy required to convert crude oil to gasoline which encompasses such things as operating the facility to convert oil to gasoline and transportion by truck of gasoline to service stations are also creating an additional drain on the available resources. However, in order to produce electricity to run an Electric Vehicle a variety of fuels can be used such as coal, atomic energy, dams and crude oil. This energy is transported to an electric vehicle by a mere wire.

In the same manner that our government dedicated itself to the conquest of space, we feel that the Electric Vehicle can achieve the same success with government support on a massive scale. Small companies such as Die Mesh Corp. have already broken some of the barriers facing Electric Vehicle acceptance and feasability, such as recharging in the home by using on-board chargers, on the road use, public exposure to mass audiences... This was done at a considerable expense to our company. We feel that once the private financial world observes our government giving financial support and confidence to this young industry, that it will soon follow with it's own financial backing, causing the Electric Vehicle Industry to grow stronger and to develop areas never before envisioned.

The major problem we find with this bill is that it may exclude the companies who have been involved in the manufacture of Electric Vehicles and who have demonstrated that they have the capability to make on the road Electric Vehicles. Small companies such as ours have invested considerable sums of money in their dedication and belief that Electric Vehicles are the transportation of the future. The money provided for under this bill, can enable a limited number of technically qualified small businesses, who have on the road Electric Vehicle experience, to participate in this project in a meaningful way. The larger automobile manufacturers should be given separate money through additional legislation, so that they too can contribute to this new industry. This bill, however, should exclude all companies or individuals who have no history of past involvement in Electric Vehicles. If the larger automakers and the "new comers" are allowed to participate with the technically qualified small companies, who have been involved in the manufacture of Electric Vehicles, it would result in such a dilution of the purposes of this bill so as to render it ineffective. The question has been asked as to where the government would get the most for it's money whether with a large auto maker or with a small business. Because of the fact that the Electric Vehicle is unique in the sense that it has no established method of construction, both a large and a small business will be starting at the same point. If the small business has been engaged in the development and manufacture of Electric Vehicles, it is in a better position to give a greater yield. A small company also has the advantage of being able to make decisions rapidly, cutting out the expensive red tape. When the smaller company receives sufficent funds it is then on a par with the larger company in the specific project of manufacturing Electric Vehicles. An example from our own experience is that the progress that the Die Mesh Corp. has made in the development and demonstration and on the road experience with an Electric Vehicle has been done with a very limited amount of money, while the same job would have cost large auto-makers millions of dollars. When all things are taken into consideration, the requirement remains that an Electric Vehicle be made and an Electric Vehicle requires more than just having the capability to make a vehicle "body." The technology involved in making auto bodies is a foregone conclusion. Therefore, we see no advantage a large company has over a small company in the making of Electric Vehicles.

In relation to the financial aspects of this bill, we feel that this bill should provide for immediate working capital in order to permit the participating companies to become immediately engaged in the goals of the bill. To do otherwise would put the progress of the Electric Vehicle precisely where it was before the bill was written. The imposition of penalties upon any participating company would tend to discourage involvement. If the penalties were incorporated into the project, they would have the potential of destroying most companies that could become involved. In this particular project, because of it's uniqueness, it is imperative that no obstacles prevent the quailified participants from becoming successful because of lack of time or money. The governments main concern should be putting Electric Vehicles on the road and not adhering to rigid time schedules or imposing of penalties.

The research and development aspect of this bill should accompany the manufacturing of the vehicles and should be performed by the same companies involved in putting Electric Vehicles on the road. The reason for this is that the companies, who are actually manufacturing Electric Vehicles, would be in the best position to understand the workings of an Electric Vehicle because of their involvement in the practical aspects of its day to day operation. The component part makers, who participate in this project, will have to consult with the Electric Vehicle Manufacturer to determine the practicality of the components and its proper application, and his research and development should be restricted to the manufacturing of component parts and not the making of Vehicles, otherwise this will dilute the efficency of the project.

DIE MESH CORP. PRECISION EXPANDED METALS

629 FIFTH AVENUE, BOX 362, PELHAM, NEW YORK 10803
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As to the battery manufacturers, their involvement should be to provide advancement in battery technology and not research and development in Electric Vehicles unless they have been previously involved in the manufacture of Electric Vehicles. The Electric Vehicle Manufacturers should provide these battery companies with Electric Vehicles to test the performance of the newly developed batteries under this program.

If all of the diverse technologies concentrate on their specialty and the specific requirements of the Electric Vehicle Manufacturers, this will produce a maximum yield.

Through the implementation of this bill, the advancement of the Electric Vehicle can go above and beyond the scope of our imagination. One of the obvious reasons by which this can happen is the fact that electricity remains to this day an unsolved mystery. This bill would start an industry with an area of sales so vast and universal that the technological advancement would be inspired by the tremendous consumer demand.

The state of the art of the industry today is comparable to the airplane and automobile industries in their infancy at the beginning of this century. We firmly believe that with your help and support progress and success can and will be achieved. In addition to submitting a biography of Die Mesh Corp. as requested by you, we are also submitting a list of revisions to the proposed bill which deal with certain items that we are unable to discuss today.

Again, we would like to express our sincere thanks and appreciation to you in allowing us to participate in this hearing.

DIE MESH CORP. PRECISION EXPANDED METALS
629 FIFTH AVENUE, BOX 362, PELHAM, NEW YORK 10803
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DIE MESH CORPORATION'S

RECOMMENDED REVISIONS
TO THE
ELECTRIC VEHICLE RESEARCH,
DEVELOPMENT AND DEMONSTRATION
ACT OF 1975

HR5470
HR6031
HR6315

DIE MESH CORP. PRECISION EXPANDED METALS

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DIE MESH CORPORATION of Pelham, New York, which has spent six years and an estimated value of over a quarter of a million dollars of its own funds in its dedication to and development of electric passenger vehicles, hereby makes the following recommendations to the Electric Vehicle Research, Development and Demonstration Act of 1975.

1. The Preface to the Bill should read as follows:

> "To authorize in the Energy Research and Development Administration a Federal program of research, development and demonstration designed to promote electric vehicle technologies and to demonstrate the commercial feasibility of electric vehicles by small businesses which are technically competent to do so."

2. Page 2, Item 2, Line 7 should read as follows:

> "(2) Our balance of payments and our economic stability are threatened by the need to import oil for the production of liquid fuel and lubricating oil for gasoline-powered vehicles and also by foreign grants and loans to maintain the balance of power in the Middle-East."

3. Page 3, Item 8, Line 3 should read as follows:

> "(8) Liquid-fuel-powered vehicles are a major source of urban noise, pollution and also highway deaths due to the excessive speed capability of the Internal Combustion Engine."

4. Page 3, Item 9, Line 7 add:

> "and will require less maintenance."

5. Page 3, Item 10, Line 10, after the word "in" insert "battery and electric drive design technology".

DIE MESH CORP. PRECISION EXPANDED METALS

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6. Page 3, Item 13, Line 20 should read as follows:

> "(13) The unimproved state of the current automobile industry would be challenged by the introduction of the new technology development by the electric vehicle industry more closely matching consumer needs."

7. Page 3, Item 14, Line 24 should be changed as follows:

> "(14) because of the large capital needs of a technically qualified small business entering into the full-scale development of this new transportation technology ...."

8. Page 4, Line 4 should read as follows:

> "desirable electric vehicle industry by technically qualified small businesses."

9. Page 4, Item 3a, Lines 11 and 12 should read as follows:

> "...tions, with companies that do not have a conflict of interest between electric vehicles and liquid fuel vehicles, in order to promote long-range conservation of liquid fuel and lubricating oil and reduce environmental pollution."

10. Page 5, Line 2, add the following list of "goals" to this Bill:

> "(5) To introduce the public to vehicles capable of being used as second cars, which do not have limitations conflicting with that use."
>
> "(6) As a primary consideration, to establish as a prerequisite for the manufacturing of electric vehicles under this program the quality of the technology of the electric drive system of the participating small business."

> "(7) To develop a vehicle body design which is suitable to accommodate an electric drive system."
>
> "(8) To provide immediate working capital to technically qualified companies which, in the past several years, have made, used and demonstrated electric vehicles."

11. Page 5, Item 1, Line 8, after the word "current" add "that can be recharged by ordinary household current by using a charger that is an integral part of the vehicle."

12. Page 5, Item 1, Lines 8, 9 and 10, which include a hybrid in the definition of an electric vehicle when it is stated that the definition of an electric vehicle also includes a non-electrical source of power designed to charge batteries or provide auxiliary power to the wheels, should be deleted as to that reference and this Bill should not include hybrids and should be restricted solely to electric vehicles.

13. Page 6, Item C-1, Line 16 should read as follows:

    > "(1) promoting basic research on electric vehicle batteries, controls, motors and variable speed mechanical drive systems."

14. Page 6, Item C-3, Line 21, after the word "contracting" add "on a non-bid basis".

15. Page 7, Item 5, after the word "structures" add "charging stations such as dual purpose parking and charging meters."

16. Page 7, Item 2, Line 17, add "and a mechanical drive system such as a variable speed drive."

17. Page 8, Item 1, Line 5, the word "significant" should be changed to the word "practical".

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18. Page 8, Item 1, Lines 8 and 9, the words "conventional chassis" should be stricken and the words "chassis designed for that system" should be put in their place and stead.

19. Page 12, Item 10, should be changed as follows:

> "Sec 10 in carrying out his functions under this Act the Administrator shall only permit technically qualified small business concerns to participate in the program under this Act."

20. Page 12, the following clause should be added at the end of the Bill:

APPEALS

> "In the event that any technically qualified small business concern shall disagree with the decision of the Administrator concerning that company's participation in this program, said company shall have the right to appeal the Administrator's decision to the appropriate governmental agency established for that purpose."

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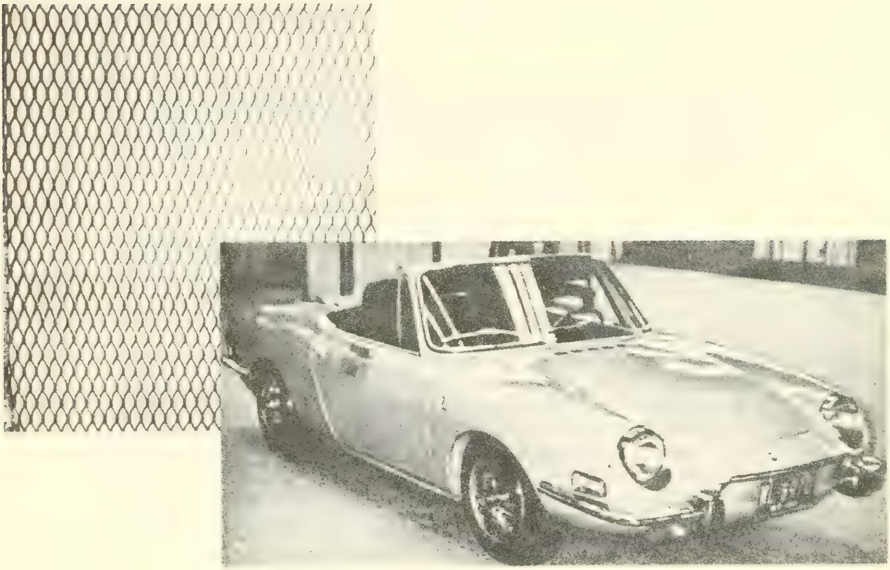
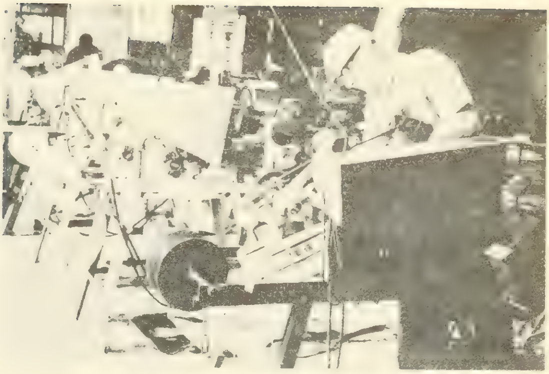
Die Mesh
Corp.

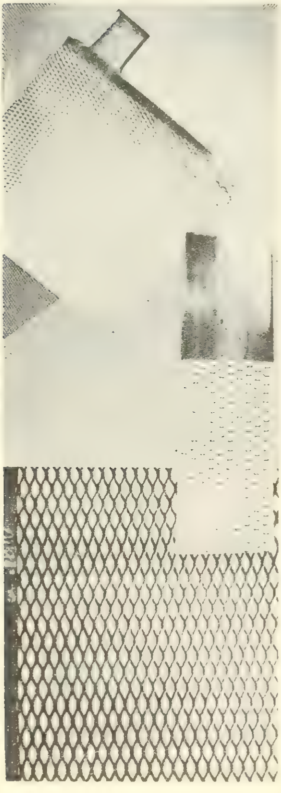


ELECTRIC CAR



EXPANDED METAL

Die Mesh



Die Mesh produces and markets expanded metal which begins as a continuous metal sheet wound on spools that pass through our patented expanding machine and is rewound on a second spool. In some cases, the metal entering the machine resembles rolled aluminium foil and after being expanded resembles window screening. A wide variety of metals are compatable to this process, including steel, copper, lead, zinc, nickel, titanium, silver and gold. The expansion of such metals has developed into a multi-million dollar market.

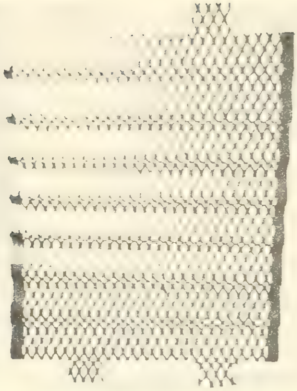
Die Mesh has become the principal supplier of expanded silver used in the batteries and fuel cells of the U.S. space program Die Mesh products have been represented in every launch from Cape Kennedy

more and more companies have been able to improve their product designs while reducing material cost.

Die Mesh can meet almost any design specification that requires expanded metal including fine mesh in precious metals and ultra-fine mesh in exotic materials. Die Mesh manufactures all of its expanded metal on its own unique machines which have been granted patents by the U.S. Patent Office.

PERFORATED METALS

of the same types and quality are also available for a variety of applications. Here, however, metal is removed as the holes are perorated but it is later recycled Large quantities of perforated metals are used by major dry battery manufacturers for electrodes, specifically in nickel cadmium batteries. A wide range of applications exist in the chemical process industries. Automotive and architectural fields utilize extensive amounts of perforated metal. Die Mesh manufactures all of its perforated metal on its own unique machines which have been granted patents by the U.S. Patent Office.

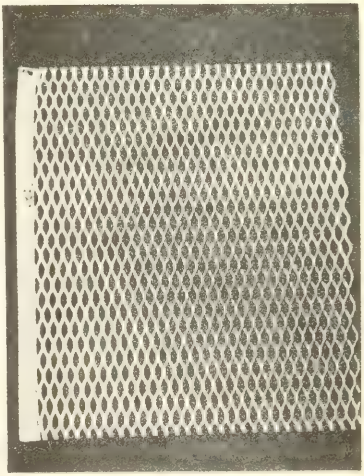


TEFLON COATING

Many combinations of expanded metals and surface finishes are available. Shown in the photo to the right is an example of Teflon coated corrugated expanded nickel with solid edges, which is used by battery manufacturers as cell separators.

ANODIZED EXPANDED ALUMINIUM

is supplied in a variety of soft-lustre colors and it can be used for an infinite variety of decorative purposes. It can be easily cut with scissors, patterned, bent and formed to the designers' requirements.



SOLID EDGE EXPANDED METAL

Die Mesh has the only patented process for producing expanded metal while maintaining a solid edge which will have innumerable advantages in the mass production of rechargeable batteries.

SECURITY

With Die Mesh from time to time expanding precious metals, provisions have been taken to provide maximum security for the facilities. Its electronic alarm system is constantly monitored by the local police department.

Facilities

FABRICATION

Die Mesh has designed and fabricated most of its equipment within its own facilities. The metal expanding machines were made at Die Mesh. High precision attained in the manufacture of each piece of equipment can thereby be assured. These machines are maintained by the same craftsmen who built them. These machines have never left the building, have never been licensed to anyone and until now have never been photographed.

PATENTS

The metal expanding machine was granted a patent by the U.S Patent Office in 1966 and five years later a patent was granted for the metal perforating machine. The key to the Die Mesh machines is that they operate with great precision at very high speeds. Additional patents for these machines and other ideas to be found on these pages are now pending.

Quality Control

Die Mesh products are unconditionally guaranteed. The company stands behind its products 100%. To do this Die Mesh has taken pains to insure that the highest quality is built into its products and that quality level is constantly being monitored by Die Mesh craftsmen.

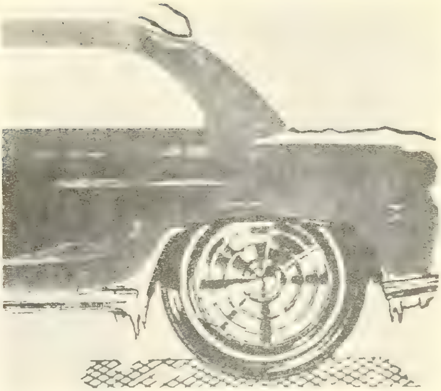
(at left) Quality Control Shadowgraph magnifies and measures conformance of expanded metal.

(at right) Quality Control Pull Tester measures the pounds required to fracture the silver mesh shown on the cover.

Consumer Products

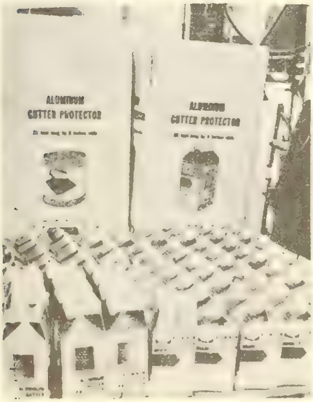
WINTER GRIP

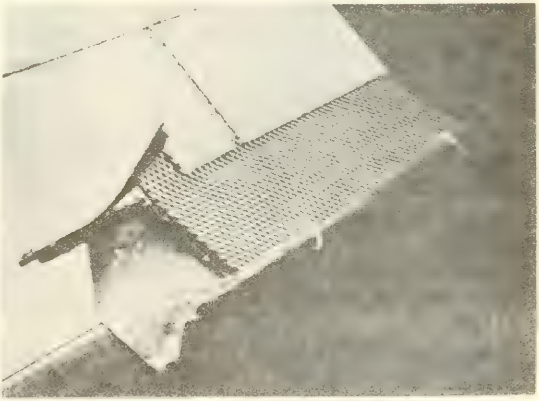
Winter Grip consists of two pieces of aluminum mesh each 5 feet long, which can be restored in its container.



It gets your car out of ice, snow or mud. Made of durable rustproof expanded aluminum, it can be used over and over again. Should be carried in every car just like a spare tire. Winter Grip is so easy to use, just place the starter edge under the sliding wheel, gently accelerate in low gear, and you're off! Available through leading auto accessory retailers.

GUTTER PROTECTOR



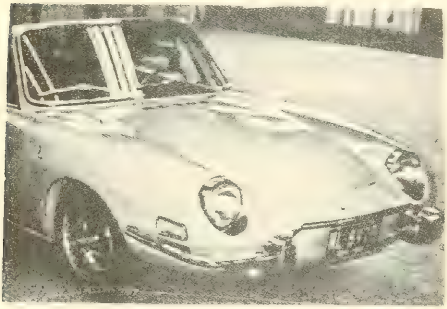


Prevents clogging of rain gutters by leaves and bird nests. Keeps snow and ice from stopping up drainage. Made of durable rust proof expanded aluminum, 6 inches wide and 25 feet long. Cuts easily with household scissors. A wise investment for the home owner.

the immediate future

SINTERING

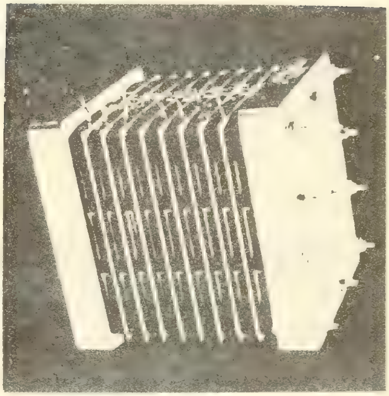
Early in 1974, Die Mesh intends to add a sintering facility to its expanded metal and electroplating capabilities. Sintering is a process of bonding a powdered nickel to a perforated or expanded strip of nickel plated steel. This extension of production capabilities will complete the three phase cycle needed to make positive electrodes, thus opening up a rapidly expanding multi-million dollar OEM market where profit margins are at least twice as high, compared to expanded metals



ELECTRA SPIDER

Press kits were issued to the Press, which resulted in stories about the car appearing in a variety of journals. Color photos of the car appeared on the front cover of May '73 issue of Electric Vehicle News which has a world wide circulation of 20,000.

the ultimate future



ENERGY THROUGH ELECTROCHEMISTRY

Man's phenomenal scientific advancement in the last hundred years has been based on a thermal combustion economy. Now man begins to realize the error of his ways and faces a fossil fuel crisis and the devasting pollution it provides. A great technological revolution based on electrochemical power conversion is now emerging. Fossil fuels will be replaced by hydrogen which is in abundant supply as H^2O (2 parts hydrogen, 1 part oxygen) commonly named water.

Water when electrolyzed separates the hydrogen and oxygen. Hydrogen creates electrical energy when it passes through a fuel cell, reuniting with oxygen to form water again, thus completing the cycle. One of the major components to be found in fuel cells is expanded metal manufactured by Die Mesh. Fuel cells resulting from electrochemical technology will lead to pollution free electrical transportation.

Die Mesh is philosophically ready for this electrochemical age and has been planning its future in the direction of the new economy for the benefit of society and corporate success.

DIE MESH CORP. PRECISION EXPANDED METALS

629 FIFTH AVENUE, BOX 362, PELHAM, NEW YORK 10803

Tel. 914 738-5444

The Die Mesh Corporation of 629 Fifth Avenue, Pelham, N.Y. has been in business for the last 13 years. During this period, its primary business has been suppling the basic substrate material for portable electrical power packs in the form of positive and negative electrodes. Typical application for these materials include the following battery types: Lead-Cells; Silver-Cells; Nickel-Cadmium Fuel Cells; Solar-Cells; and almost all research and development programs that have been tested and are presently being tested, employing the concept of expanded or perforated metal substrate.

THE PRINCIPAL USES FOR THESE PORTABLE ENERGY SOURCES HAVE BEEN IN THE FOLLOWING AREAS.

CONSUMER PRODUCTS	MILITARY	SPACE	GOVERNMENT
FLASH LIGHTS	AIRCRAFT	COMMUNICATION SATELLITES	USED IN ELECTRIC CAR
AUXIILLARY LIGHTING	LAND COMMUNICATION		BATTERY EXPERIMENTS
TOOTH BRUSHES (COSMETIC TOOLS)	AUXILLARY & STAND-BY	SPACE EXPLORATion	
PORTABLE POWER TOOLS	EQUIPMENT		SOLAR CELL, SILVER CELL
PORTABLE OUTDOOR COOKING ITEMS		LUNAR TRAVEL, LAND ROVER	FUEL CELL & NICKEL
EMERGENCY LIGHTING &	MARINE EMERGENCY		CADMIUM RESEARCH
ALARM SYSTEMS	AUXILLARY NAVAL	SPACE EXPLORATION & DEVELOPMENT	

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CONSUMER PRODUCTS	MILITARY	SPACE	GOVERNMENT
PORTABLE COMMUNICATION SYSTEMS	APPLICATION	COMMUNICATION	
ELECTRIC CAR PROTOTYPE BATTERIES			
MAJOR BATTERY MANUFACTURERS FOR MAJOR AUTO MANUFACTURERS			

By reason of its knowledge and involvement in the battery field, in 1969 the Die Mesh Corp. decided it would become involved in the development and manufacture of Electric Vehicles of its own design.

After 3 years of research and development, the Die Mesh Corp. has been engaged in the continuous exhibition of its own Electric Vehicles reconstructed from existing gasoline vehicles. Contained in its Electric Vehicles is its unique Electric Drive System for which the company was granted a patent by the United States Patent Office. The Corporations Electric Vehicles have been exhibited throughout the county of Westchester, N.Y. and have received wide spread attention at various International and Greater New York Auto Shows at the New York Coliseum and in Washington, D. C. Auto Shows, commencing in 1973 with the introduction of its Electra-Spider. Further, the companys Electric Vehicle entered and completed the "1969 Clean Air Car Race" from New York to California.

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The Die Mesh Corp. has been and will continue to be an intergal part of the future development of the battery and fuel cell. However, it has also committed itself to becoming a leader in the manufacture of Electric Vehicles. In conjunction with this goal, Die Mesh Corp. is prepared to provide battery and fuel cell manufacturers with materials and battery experience, that will not only advance battery technology and design but will improve the state of the art of Electric Vehicles.

The Die Mesh Corp. started in a one car garage 13 years ago and is presently located on a 4½ acre Industrial Site with a total of 80,000 square feet of manufacturing space. The Die Mesh Corp. owns the Real Estate upon which it is located.

The Die Mesh Corp. has undergone continuous growth from the time of its inception. This growth has been inspired by the companys faithful investors and the belief that consumer need preceeds business growth. This principal, at this point in time of energy crisis specifically applies to the manufacture of Electric Vehicles to which Die Mesh Corp. is dedicated.

DIE MESH CORP.

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THREE PHASE PROPOSAL FOR THE ADMINISTRATION OF THE ELECTRIC VEHICLE RESEARCH, DEVELOPMENT AND DEMONSTRATION ACTS OF 1975.

Dated, July 25, 1975.

DIE MESH CORP.

DIE MESH CORP.

629 FIFTH AVENUE, BOX 362, PELHAM, NEW YORK 10803
Tel. 914 738-5444

July 25, 1975.

PHASE I

PLACING THE TECHNICALLY QUALIFIED SMALL COMPANIES IN A FINANCIALLY HEALTHY POSITION

All small companies who have no record of profitable sales, but who have successfully demonstrated their ability and desire to accomplish the goals and aspirations of HR 5470, should be given retroactively, grants equal to the estimate of the administrators calculated cost for such a product. This would permit those companies to survive the necessary time the administrator would need so that he may exercise sound technical judgment as well as good business practice to insure the success of the project. By reason of the fact that these small companies have struggled to survive the rigors of a business that produced no actual sales, but were ahead of their time in the development of EV's which have now become an absolute necessity, they have suffered great financial losses, thereby substantially weakening their company. This will continue if financial support, along with consumer education, is not given immediately forcing these technically qualified companies out of business. These small businesses will positively qualify for the program as originally offered. However, if the administrator is compelled by legislative decision to delay the dispensation of dollars so that it can maintain the state of the art that the small EV companies have brought it up to, the subsequent damage to the ailing industry will be devastating to

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the point of extinction. At that point the only remnants of the EV business will be the larger companies and paper companies, none of which will have prior electric vehicles "on the road experience" necessary to make this project a success.

PHASE II

GUARANTEED LOAN PROGRAM

The second phase should be the guaranteed loan program. This program will aid both the administrator and the small company. The allowable loan maximum should be equal to an amount suitable to allow the borrower to insure the administrator that the necessary tests and time evaluation will not destroy the companies that are presently on the road with EV's and that are anxious to participate. These companies must be kept viable and healthy. The maximum limit should be $5,000,000.00. It should be clearly understood that these small companies consist of more than just one individual. Closer examination will disclose that they consist of people who have the same beliefs that the company management has and that these people demonstrated their belief by investing money in this young EV industry. However, because the driving public is not aware of the real crisis of the petroleum oil shortage, the effect that fuel emissions have upon all plant and animal life and their own limited driving patterns, these investors that have been ahead of their time have not been able to interest others because of the lack of interest by the government and the financial world.

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PHASE III

PLANNING GRANTS

The third phase should be planning grants. The amount of dollars required to do this job should be sufficient to do the following:

1. Estimate the time and cost to procure difficult to botain parts and components.
2. To order and test these components from at least two manufacturers.
3. Set up a buying group to do the same as above on easy to buy parts and components.
4. Evaluate delivery and quality of companies that would be asked to bid on easy to buy parts.
5. Buying group to estimate, locate and evaluate equipment necessary for parts and assemblies to be made by the EV companies.
6. Personnel manager to assemble by interview the necessary professional and craft people--cost availability and reliability and similar work experience.
7. Planning group to lay out existing space for limited car production that will have the potential for larger production.
8. Establishment of a management group.

Battery manufacturers need only to improve their product by structuring them so that they will become more reliable and compatible with the precise requirements of the electric vehicles. Component manufacturers of present I.C.E.'s need only to alter their design and parts so that they are suitable for EV's. Therefore, it cannot really be called development but it should really be called redesign. At the present time because these components, including batteries, did not have the EV in mind when they were designed, they cannot contribute any significant developments to EV's. However, with proper guidance from manufacturers of on the road EV's, these components can contribute meaningfully.

COMMENT ON THE HYBRID

H.R. 5470 states clearly that it is for electric vehicles. In order for it to succeed, the administrator should not be burdened with anything that is not in the true sense a completely electric vehicle, otherwise the bill becomes subverted in its intent and diluted into total ineffectiveness. Hybrids are apoor excuse for the gas engine. The gas engine is a magnificent work of art and engineering. It should not be diluted by the so-called hybrid. We, in the electric EV business would like to think that some day I.C.E.'s will fade out as the horse and buggy of yesteryear. However, for the time being, it is a far more superior mode of transportation than the hybrid can ever expect to be. Therefore, good common sense teaches that as an EV the hybrid cannot be successful because of its additional burden and mechanical--electrical losses and as an I.C.E. it is far inferior. EV's can develop only if we do not confuse the goals by expecting through some miracle to develop the perfect replacement for the I.C.E. It took sixty years for the I.C.E. to develop; let's give the EV time to perform and not choke it off. The end result if hybrids are included in this bill, will be that all focus will thereafter be on developing a " better hybrid" and not the continuous advancement of electric vehicles, which will definitely come if given the proper chance. The hybrid will not solve the fossil-fuel crisis nor the pollution of our nation's cities; however, the electric vehicle will.

DIE MESH CORP.
By

Dominic Borelli, Pres.

Mr. Borello. I'd like to also introduce Mr. Dante Alberi, vice president of Die Mesh Corp.

Mr. McCormack. Welcome, Mr. Alberi.

Mr. Borello. I would like to thank this committee for giving the Die Mesh Corp. the opportunity to testify concerning various aspects of the Electric Vehicle Research, Development and Demonstration Act of 1975. We feel that our on-the-road experience with our own electric vehicle over the past 6 years can contribute to the understanding and implementation of this bill.

For the past 6 years the Die Mesh Corp. has committed itself to placing an electric vehicle of its own design on the road. We have attempted to demonstrate to the consumer, not only the feasability of an electric vehicle, but also its safety and low maintenance characteristics through exhibiting our vehicles in both exhibitions and on-the-road use. If the Die Mesh Corp. throughout this period had sufficient financing to mass produce these electric vehicles, our commitment would now be a reality and this bill would not now be necessary. However, all our efforts to raise capital for the mass production of electric vehicles have been totally unsuccessful.

Neither the private financial world nor any of our governmental agencies have been willing to finance a venture such as this in a meaningful way. In relation to the oil crisis, we feel American money has been used to solve emergency problems for foreign countries, thus placing our country in a deficit position and weakening our economic stability.

Our Nation is now in a two-fold crisis. First, the people of our cities are being choked by the fossil fuel pollutants and, second, the average U.S. citizen is on the verge of being priced right out of the gasoline market with the next increase in the cost of gasoline. We feel the mass production of electric vehicles can provide short term relief and a long term permanent solution to these problems. For example, the energy required to convert crude oil to gasoline which encompasses such things as operating the facility to convert oil to gasoline and transporting by truck of gasoline to service stations are also creating an additional drain on the available resources. However, in order to produce electricity to run an electric vehicle a variety of fuels can be used, such as coal, atomic energy, dams and crude oil. This energy is transported directly to the consumer in the home to an electric vehicle by a mere wire.

In the same manner that our Government dedicated itself to the conquest of space, we feel that the electric vehicle can achieve the same success with Government support on a massive scale. Small companies such as Die Mesh Corp. have already broken some of the barriers facing electric vehicle acceptance and feasability, such as recharging in the home by using on-board chargers, on-the-road use, public exposure to mass audiences. This was done at a considerable expense to our company, in excess of $250,000. We feel that once the private financial world observes our Government giving financial support and confidence to this young industry, that it will soon follow with its own financial backing, causing the electric vehicle industry to grow stronger and to develop in areas never before envisioned.

The major problem we find with this bill is that it may exclude the companies who have been involved in the manufacture of electric vehicles and who have demonstrated that they have the capability to make on-the-road electric vehicles. Small companies such as ours have invested considerable sums of money in their dedication and belief that electric vehicles are the transportation of the future. The money provided for under this bill can enable a limited number of technically qualified small businesses, who have on-the-road electric vehicle experience, to participate in this project in a meaningful way.

The larger automobile manufacturers should be given separate money through additional legislation, so that they too can contribute to this new industry.

The present bill, further, should exclude all companies or individuals who have no history of past involvement in electric vehicles.

If the larger automakers and the "newcomers" are allowed to participate with the technically qualified small companies, who have been involved in the manufacture of electric vehicles, it would result in such a dilution of the purposes of this bill so as to render it ineffective.

The question has been asked as to where the Government would get the most for its money, whether with a large automaker or with a small business. Because of the fact that the electric vehicle is unique in the sense that it has no established method of construction, both a large and a small company will be starting at the same point. If a small company has been engaged in the development and manufacture of electric vehicles, it is in a better position to give a greater yield. Small companies also have the advantage of being able to make decisions rapidly, cutting out the expensive redtape. An example, from our own experience, is that the progress that the Die Mesh Corp. has made toward giving this vehicle major credibility, and this was done with a very limited amount of money, while the same job would have cost large automakers millions of dollars. The primary factor to be considered in determining the proper classification of electric vehicle manufacturers is their ability to produce a total electric vehicle, and not the ability to produce auto bodies. Therefore, we see no advantage a large company has over a small company in the making of electric vehicles.

In relation to the financial aspects of this bill, we feel this bill should provide for immediate working capital in order to permit the participating companies to become immediately engaged in the goals of the bill. To do otherwise would put the progress of the electric vehicle precisely where it was before the bill was written. The imposition of penalties upon any participating company would tend to discourage involvement. If the penalties were incorporated into the project, they would have the potential of putting small companies out of business. Because of its uniqueness, it is imperative that no obstacles prevent the qualified participants from becoming successful because of lack of time or money. The Government's main concern should be putting electric vehicles on the road and not adhering to rigid time schedules.

The research and development aspect of this bill should accompany the manufacturing of the vehicles and should be performed by the same companies involved in putting electric vehicles actually on the road. The reason for this is that the companies who are actually manufacturing electric vehicles would be in the best position to understand the workings of an on-the-road electric vehicle because of their involvement in the practical aspects of its day-to-day operation. The component part makers, who participate in this project, will have to consult with the electric vehicle manufacturer to determine the practicality of the components and its proper application. Therefore, their research and development should be restricted to the manufacturing of component parts and not the manufacturing of vehicles. Otherwise, this will dilute the efficiency of the project.

As to the battery manufacturers, their involvement should be to provide advancement in battery technology and not research and development of on-the-road electric vehicles unless, of course, they have previously been involved in the manufacture of electric vehicles. The electric vehicle manufacturers should provide these battery companies with electric vehicles to test the performance of the newly developed batteries in actual use.

If all of the diverse technologies concentrate on their specialty and the specific requirements of the electric vehicle manufacturers, the net result will produce a maximum yield.

Through the implementation of this bill, the advancement of EV's can go above and beyond the scope of our imagination. One of the obvious reasons by which this can happen is the fact that electricity remains to this day an unsolved mystery. This bill would start an industry with an area of sales so vast and universal that the technological advancements would be inspired by the tremendous consumer demand.

The state-of-the-art of the industry today is comparable to the airplane and automobile industries in their infancy. We firmly believe that with your help and support the same progress and success will be achieved with EV's.

We would like to express our sincere thanks and appreciation to you for allowing us to participate in this hearing.

Mr. McCormack. Thank you very much, Mr. Borello.

Mr. Ottinger, would you like to go first?

Mr. Ottinger. Thanks very much, Mr. Chairman.

We had testimony earlier with respect to your statement of the need for working capital by another witness, suggesting that in addition to the financing of experimental vehicles and purchase of vehicles as provided in this act, that we have a provision for Government-guaranteed loans to manufacturers.

Is this a kind of provision that you think might help your situation, in terms of raising working capital?

Mr. Borello. Yes; I think that is an excellent provision. As a matter of fact, it is long overdue, and we would gladly accept that as a means of getting to an end.

Mr. Ottinger. We are having the committee staff attempt to draft something up in that regard for consideration. I think it might answer some of the problems of corporations such as yourself in this area.

You talk about penalties, and I think that is addressed to a different kind of problem than is envisioned in this bill. As I understand it, to bid on the post office contract, the penalties provided in that solicitation for bid were such that you felt it was too much of a risk for you to take?

Mr. BORELLO. That is correct. As a matter of fact, we took the same stance that Mr. Aronson did. We felt that if we bid we could lose our company, and we want to make electric cars desperately, but we still want to have a company, and we just thought that it wouldn't be a good choice to make at that time.

Mr. OTTINGER. I do not think that there is anything in this legislation that would contemplate penalties.

Mr. BORELLO. No. But we thought that the administrator might take it upon his own to decide that he would impose penalties in order to expedite the manufacture of the vehicles.

Mr. OTTINGER. Are there any other provisions that you think are needed to protect small business participation?

Mr. BORELLO. We submitted some revisions, and I believe the committee has copies of all of them, and I think they deal mostly with small companies, and the fact that maybe the time period might be a little tight. Penalties that might be imposed would create such a disenchantment on the part of most people, even if one tried to get involved.

Mr. OTTINGER. In the revision that I proposed for committee consideration, it is proposed that 50 percent of the funds be reserved for other than the major automobile companies.

Mr. BORELLO. We feel that's equitable. We also feel that the larger automobile companies can contribute quite a bit toward the production and the eventual development of the electric vehicle, and we just felt that the money that is now allotted—and I know that your bill had $150 million, which is slightly more than this other bill had, which was $120 million—we just feel that there is such a desperate need for this that if you do want to get the larger companies involved, that they should be involved in kind of a different set of rules.

I would say that the 50 percent sounds equitable, but I really don't know all of the details, when you get down to actually calculating what it's going to cost to set up the production for these small companies.

Mr. OTTINGER. I must say that I am concerned. The major automobile companies ought to be able to have the capital to do this kind of development themselves. If they have not done it, one suspects that they have such inertia that they really are not anxious to see the development of a vehicle that would require them to change their entire production line. We have seen that, of course, with the compact car. There is a tremendous resistance.

On the other hand, to really get this development out, if you can stimulate the major companies to get involved, I think it would be a good thing. So we will have to compromise on that.

Mr. BORELLO. Might I suggest that the portion of the bill, or the part that you would like to add, which is the guarantees of loans, could apply to the large business as well, and if that be the case, the $120 million, I suppose, could be a lot more if you take it in that sense.

Mr. OTTINGER. It would be at no cost to the Government.

Mr. BORELLO. It would be at no cost to the Government if everything worked out for the manufacturer. He'd be on his own. So that actually you might end up with very little money that Uncle Sam has to shell out, so to speak.

Mr. OTTINGER. I thank you very much for your contribution, and taking the time and trouble to come down here. We appreciate having you. As I said, we're proud to have you in our district.

Mr. BORELLO. I would just like to say this, if I might: That right now we're talking about the feasibility of electric vehicles, and Die Mesh Corp. has one running in Westchester now doing errands and all kinds of things, and the batteries are fine, we have no complaints about them.

Mr. MCCORMACK. That is great, Mr. Borello, and I want to say that you have a worthy champion in Congressman Ottinger. He has worked very, very hard for you and for his beliefs and philosophies here on energy. He is doing a great job, and you can be very proud of him.

Mr. OTTINGER. Thank you, Mr. Chairman.

Mr. MCCORMACK. Mr. Brown, before I ask you if you have any questions, I want to say that this morning I overlooked something. I committed a faux pas, and I apologize for it. Mr. Tom Moss, who is sitting over here, was highly instrumental in getting this legislation drafted, and when I took credit for this bill this morning and credited it partly to my staff, I was speaking in the concept of the demonstration program. But Mr. Brown had been working on this for a long time, and Mr. Moss did a great deal of the work on the bill that I was not particularly aware of because it sort of went between my original idea and having a piece of paper in my hand.

So, Tom, I want to apologize to you and to express my appreciation and praise for the workmanship.

Mr. BROWN. You better get the bill passed.

Mr. MCCORMACK. I beg your pardon?

Mr. BROWN. You better get the bill passed.

Mr. MCCORMACK. We are going to get the bill passed together, Mr. Brown. [Laughter.]

I have no further questions.

I do want to say I thank you very much for your detailed recommendations with respect to the bill. Mr. Borello, will undoubtedly have the staff going through these and evaluating them, and we will be looking at them and considering them as we work toward making a clean bill.

I believe I saw your car. Your car was here Tuesday morning, was it not?

Mr. BORELLO. Yes.

Mr. MCCORMACK. I saw that, and as a matter of fact, I believe that we had the hood up and we were looking at that car when the television people came along. My wife told me that she saw me on TV. It was your car that we had.

Mr. BORELLO. We had 4 minutes in New York City, by the way, on channel 7 at 9 o'clock in the morning.

Mr. MCCORMACK. That is great.

Mr. BORELLO. That should help us quite a bit in this bill.

Mr. MCCORMACK. Are there any other questions, or do any other members of the committee have any comments?

[Answers to additional questions submitted to Mr. Borello follow:]

DIE MESH CORP. PRECISION EXPANDED METALS

629 FIFTH AVENUE, BOX 362, PELHAM, NEW YORK 10803

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DIE MESH CORPORATION'S ANSWERS TO ELECTRIC VEHICLE QUESTIONAIRE DATED JULY 10, 1975 FROM HONORABLE MIKE McCORMACK

Answering Question 1: There is an absolute need for federal financial aid at this point and time for the electric vehicle industry. Due to the fact that the fossil--fuel crisis descended upon this country without any prior warning, the technically qualified small companies could not possibly have become prepared to meet the goals of H.R. 5470 on such short notice. For the same reasons private financial institutions also did not have sufficient time to analyze electric vehicle industry potential and feasibility. However, the United States government because of its R & D activities in the energy field and its ability to investigate the particular areas through its congressional facilities and related public hearings, has been able to determine the definite feasibility of electric vehicle at this juncture due to the statistical data concerning limited driving patterns of 80% of all United States drivers. It also has been determined that the pollution created by vehicles in our cities has now entered the realm of crisis proportion.

Never in our country's history has there been more reasons to aim at phasing out fossil--fuel by a progressive replacement program with electric vehicles in the State of the Art as it exists today and the immediate advancements that will follow.

The federal financial aid that will be given as a result of H.R. 5470 will be returned as a benefit to our government in the following ways.

(1) The use of electric vehicles on a mass scale throughout this country will eliminate the tremendous cost that is being poured into the vehicle anti-pollution devices and controls.

(2) The scarce fossil--fuel which will be saved as a result of the mass use of E.V.'s can be better used by our nation's industry until other forms of energy are developed. The time that the use of electric vehicles will buy for industry may boil itself down to a question of survival for our country.

(3) The third benefit will be a new approach to automobile as it relates to safety, practicability and design developments; which have been stagnant for many years. Advancements of this sort can only develop if the new small companies are not compelled to rely on old chassis and old ideas but rather are left to their own resourcefulness and inventness. The anticipated innovations from the production of E.V.s has, in the past, cost the major

auto makers sums of money in excess of the monetary allotment under H.R. 5470. The resourcefulness of small companies, their desire to be successful and their present knowhow, coupled with the proper financing, will yield advancements that cannot now be anticipated. Man's vision has never exceeded God's gifts.

Our company has estimated that the cost to set up the necessary plans to manufacture EV's in order to participate in H.R. 5470 and thereafter for the continuous production of these vehicles to meet consumers' needs, will be approximately $15,000,000.00. The following is an estimated cost analysis for our participation as stated aforesaid.

COST ANALYSIS

1.	Rental of 7,500 square feet - $36,000.00 per year . . .	$108,000.00
2.	Renovating and adapting the present premises to electric vehicle manufacturing (first year only)	300,000.00
3.	Procuring additional premises for manufacturing (first year only)	200,000.00
4.	Installation of necessary equipment and machinery (first year only)	1,000,000.00
5.	Employment of approximately fifty (50) people - $700,000.00 per year	2,100,000.00
6.	Acquisition of raw materials calculated at $2,100,000.00 per year	6,300,000.00
7.	Purchased parts, calculated at $400,000.00 per year .	1,200,000.00
8.	Installation of a fiberglass moulding operation (first year only)	500,000.00
9.	Development of three prototypes	650,000.00
10.	Three year follow-up program	3,200,000.00
	$	15,558,000.00

It is obvious from this analysis that only the federal government is capable of financing this program sufficient to insure its success and thereby serve the public in general by improving the environment and providing a means for their daily transportation even when fossil--fuels cease to exist.

An important point to be considered is that through the excitement generated by our government's participation in this program, the private financial world will take over where H.R. 5470 leaves off, thereby relieving the government of any further cost.

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Answering Question 2a:	Electric vehicle industry is presently limited to a very small number of technically qualified devoted small companies whose finances are limited.
Answering Question 2b:	The industry is limited by capital, poor public relations and consumer unawareness of their limited driving patterns.
Answering Question 3:	The best means will be to give each company that is qualified the same amount of vehicles to produce, and also to provide three advance prototype models. At this point it should be noted that this project should not include newcomers to the electric vehicle industry because they would require at least a three year test period from the point that they perfect their electrical drive system. Only then can they even begin to order the necessary components to produce their vehicle on a mass scale. Only companies who have had "on the road experience" can make a success out of H.R. 5470. The Administrator should be made aware of the fact that if the financing under H.R. 5470 is diluted to too many companies or if inexperienced companies are chosen to participate, then H.R. 5470 is doomed to failure.
Answering Question 3a:	No, this program should not be implemented on a bid basis. For the best result, technically qualified companies should be chosen to participate.
Answering Question 3b:	Yes, provided that the loans are for a long term and at a low interest rate and that they are accompanied by the funds alloted in this bill.
Answering Question 3c:	Yes.
Answering Question 3d:	The qualified companies should be alloted equal capital and assigned the same goals at the end of the three year period. Those that survive and produce a superior product should be given further support, if necessary.
Answering Question 3e:	Because of the uniqueness of the product and the program, the primary advantage consists solely with the technically qualified electric vehicle companies that understand and are capable of producing an "on the road" electric vehicle. The small companies that are presently in the business will therefore, have the obvious advantage. The larger companies would have a substantial dis-

advantage because of their built-in bureaucracy. When it comes to the production of EV's the advantage is in "the understanding, not the size".

Answering Question 3f:	This program should rely completely on United Stated products and parts, and also be limited to United States electric vehicle companies. Safety factors should be equal to the gas car at the point in its history when its speed was approximately 45 miles per hour. For the most part safety, as always, will depend upon the driver.
Answering Question 4:	Excellent.
Answering Question 5:	The only barrier that remains is the consumer. The reason for his resistance up to this point is that he is completely unaware of his limited driving patters (range and speed).
Answering Question 6:	No, to the contrary electric vehicles will eventually be less of a maintenance problem than the gas engine because an electric vehicle has less moving parts that will require maintenance.
Answering Question 7:	No, this effort must rely on small companies who can move swiftly unencumbered by the big corporate bureaucracy. Once the initial cars have been put on the road and are being used daily, at that time the larger companies would be in a position to assist in the mass distribution and manufacturing of electric vehicles using their own capital.
Answering Question 8:	Using an old chassis could cause this project to suffer in performance and maintenance. The configuration of the total figure must be compatible with the electric drive system and the batteries. Given the proper capital and sufficient time the smaller more qualified companies would perform to full satisfaction.
Answering Question 9:	Adjusting to a different mode of driving.
Answering Question 9a:	Electric vehicles are safer at this time because of their lower speed and do not contain the hazard of making pollutants and do not carry a fuel that is dangerously inflammable and explosive.
Answering Question 9b:	The hazards would apply only if a vehicle is involved in an accident so severe that there would probably be no survivors and perhaps to the maintenance man if he is careless.

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Answering Question 10: As the government R&D projects are all aimed at providing more electricity, it would seem that this is the way to go in view of the fact that the life of fossil--fuels at current rate of consumption will soon be gone.

Answering Question 10a: Yes where it is possible.

Answering Question 10b: This should be a separate bill with its own capital allotment.

Answering Question 10c: The fuel cell, if it can be properly developed to adopt itself to an electric vehicle, would make an excellent source of fuel. However, any and all power supplies will always be secondary to an efficient drive system. For example: in examining the history of the gas engine it is interesting to note that the fuel (gas) remains unchanged, but that the engine and its development was responsible for the acceptance of the gas automobile by the public.

Answering Question11 & 11a: The basic objectives are endurance, uniqueness of design and ability to provide the consumer with a driving range consistent with the intent of H.R. 5470. This project should be limited to technically qualified electric vehicle companies who have been active in development and actual "on the road" use of EV's for a number of years, sufficient to be capable of determining the value and endurance of its electric drive design and the feasibility of going into production with that design which can only come from documented prior experience.

Answering Question 11b: There should be a flexibility in the time schedule to allow certain companies to first assemble their operation and thereafter go into production. Speed may force some manufacturers to take short cuts that would be detrimental to the product and therefore, the overall success of the program. However, it should be realized that most manufacturers would be anxious to complete ahead of time. Each company should be limited to approximately 1,000 electric vehicles and three prototypes.

Answering Question 11c: This would delay the essential and primary advancement of the development of an efficient electrical drive system that will ultimately match and most probably better the present gasoline engine car.

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Answering Question IId: Electric vehicle manufacturers are the only ones capable of telling the battery manufacturers the design required to improve the vehicle that they presently make.

Answering Question IIe: Already answered in the answer to Question "I"; there is no cause for doubt that the batteries as they exist today are capable of doing the job.

Answering Question IIf: The cost of petroleum we know, will rise. However, it will be impossible to estimate an industry where R&D in both electricity and EV's could be dramatic.

Answering Question 12: No, for the following reasons: As it is not our purpose to discourage different types of vehicles, we suggest that you consider what a hybrid consists of. (I) A complete electrical system combined with a complete gas engine system, including gasoline fuel; (2) It should perform equally to other types of electric vehicles in spite of the fact that it is carrying the gas engine system plus gas; (3) The gas engine system must perform equally to some other similar gas engine vehicles in spite of the fact that it is carrying a complete electric vehicle system including batteries; (4) It must include all of the safety factors for high speed vehicles; (5) It must be heavier and better supported in its chassis design to carry the two systems; (6) It will require electrical and mechanical maintenance stations; (7) This hybrid system may result in consuming gasoline and making pollution equal to a compact car gas engine because of the above factors.

Comment: Question "12" clearly indicates to us that an attempt is being made to make an electric vehicle perform equal to a gas engine. At the present time electric vehicles are in a class by themselves and will perform in the following manner based upon our own "on the road experience" for the past five years; a 2600 pound vehicle including batteries, can travel from 35 to 42 miles at speeds between 45 to 55 miles per hour on a single charge. This distance would resemble a drive route that would include steep uphill grades, highway driving and intown driving. The DIE MESH vehicle is presently in use doing all of the aforesaid commencing with driving to work each morning and performing all company chores. Thereafter, the vehicle is driven home and subsequently used as a second car for the evening. At the end of

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the average day the vehicle is put on charge using an on-board charger and ordinary household current. The cycle is repeated again the next day. On all the Die Mesh electric vehicles we have placed 30,000 miles over the past five years. As we have previously noted, the road block that the electric vehicles have been faced with is the public who are not aware of their own limited driving range and use. It is fully capable of doing the job for the majority of todays consumers without the necessity of being a hybrid.

Answering Question 13: Yes.

Answering Question 14: From our experience with the Die Mesh vehicles, which have been on the road in Pelham, New York, for the past five years performing all the everyday chores of ordinary ICE's including going on the open highway for a total mileage of approximately 30,000 miles, there never has been one accident. These vehicles have been driven by a varied assortment of people who have merely practiced good driving habits. Therefore, the key to safety has always been the drive.

DIE MESH CORP.

Mr. McCormack. Again, I want to thank you very much, all of you, for coming.

We will pick up these hearings tomorrow morning again at 10 o'clock. Thank you all very much.

[Whereupon, the subcommittee adjourned at 2:58 p.m., to reconvene at 10 a.m., on Friday, June 6, 1975.]

ELECTRIC VEHICLE RESEARCH, DEVELOPMENT, AND DEMONSTRATION ACT OF 1975

FRIDAY, JUNE 6, 1975

House of Representatives,
Committee on Science and Technology,
Subcommittee on Energy Research, Development,
and Demonstration,
Washington, D.C.

The subcommittee met, pursuant to adjournment, at 10:08 a.m., in room 2318, Rayburn House Office Building, Hon. George E. Brown, Jr. (acting chairman of the subcommittee) presiding.

Mr. Brown. The subcommittee will come to order.

This is the fourth day of hearings of the Subcommittee on Energy Research, Development, and Demonstration on the Electric Vehicle Research, Development, and Demonstration Act of 1975.

Chairman McCormack, who has been the leader in the development and the presentation of this legislation, is going to have to leave shortly and has asked me to preside this morning because of that, and I will seek to do so in a manner befitting his excellent example.

At this point I would like to have inserted in the record a statement by the ranking minority member of the committee, Congressman Goldwater, without objection, and the statement of the chairman of the subcommittee also, without objection.

[The statement of Mr. Goldwater follows:]

Remarks by Mr. Goldwater, June 6, 1975

I want to take this opportunity to comment on the excellence of these electric vehicle hearings this week. They have served well to identify the obvious differences in the Government and within industry regarding the ready availability of reasonably competitive technology, the timing of the demonstrations, the best means to include both large and small businesses while protecting small businesses and the type of support the government should give. All of the witnesses this week should be commended for their testimony and for focusing their comments on these four key issues in the bill. I am particularly looking forward to the testimony today of Mr. Holzwarth of General Motors representing our largest auto manufacturer and each of the subsequent witnesses who represent small manufacturers regarding these issues. Certainly, we will be much better prepared to further consider H.R. 5470 as a result of all of this testimony. Let me conclude, Mr. Chairman, by commending our staff for the thoroughness of the preparation of the hearings and the excellence of the witnesses and testimony we have received. I specifically wish to commend Dr. Lloyd Currie and Dr. Tom Moss for their efforts preparatory to these hearings.

Mr. Brown. Our first witness this morning is a representative of General Motors, and since we have a distinguished member of the committee from Michigan—in fact, we have two distinguished members from Michigan, but one of them is here—I'm going to ask Congressman Blanchard if he will introduce the gentlemen from General Motors who, I presume, are constituents of his, and say something nice about them. Mr. Blanchard.

Mr. **Blanchard.** Thank you, Mr. Chairman.

I am privileged to represent the 18th District of Michigan, which includes a large part of the suburbs of Detroit, and in that district is the General Motors Technical Center, in addition to a number of other auto and auto-related companies.

One of the things that people don't always understand is that the Big Three and other auto-related manufacturers have been involved in pioneering some new concepts to pave the way for the future with the use of the automobile in energy efficiency.

Yesterday we had a fellow named Mr. Robert Aronson from Troy, who is from a smaller firm, and I'm sorry I couldn't be here to present him to the committee.

But today we do have with us representing General Motors, Mr. James Holzwarth, who is technical director of the General Motors Research Laboratories, and he will make a statement. Accompanying him is Paul Agarwal, who is head of the Research Laboratories' Electrical Engineering Department.

Before they proceed I should mention that they do have an electric vehicle downstairs in the Horseshoe and, like the others that we've been looking at, it will be available for inspection and, I suppose, a ride after the testimony.

So it's my pleasure to present Mr. Holzwarth and his associate, Mr. Agarwal.

Mr. **Brown.** Gentlemen, we welcome you here, and we're very pleased that you're here to offer your testimony on behalf of General Motors.

I hope we'll be able to get down to see your automobile, and we hope you get it into production on a large scale next year.

Without objection, the testimony in full will be included in the record at this point, and you may proceed, either to read it, or summarize it, as you see fit, Mr. Holzwarth.

STATEMENT OF JAMES C. HOLZWARTH, TECHNICAL DIRECTOR, GENERAL MOTORS RESEARCH LABORATORIES; ACCOMPANIED BY PAUL D. AGARWAL, HEAD OF ELECTRICAL ENGINEERING DEPARTMENT, GENERAL MOTORS RESEARCH LABORATORIES

Mr. **Holzwarth.** Thank you, Mr. Chairman.

[The statement of James C. Holzwarth follows:]

Statement of
General Motors Corporation
to the

Subcommittee on Energy Research,
Development and Demonstration
of the
House Committee on Science and Technology

on
H.R. 5470
Electric Vehicle Research, Development, and
Demonstration Act of 1975

Presented by
James C. Holzwarth
Technical Director
General Motors Research Laboratories

Washington, D.C.
June 6, 1975

Mr. Chairman and members of the House Subcommittee on Energy Research, Development and Demonstration, I am James C. Holzwarth, technical director, General Motors Research Laboratories. With me today is Paul D. Agarwal, head of Research Laboratories' Electrical Engineering Department. We appreciate the opportunity to comment on H.R. 5470.

As we move toward energy self-sufficiency, when presumably nearly all of our electric power will be derived from coal and/or nuclear sources, and large scale use of petroleum and natural gas by public utilities will no longer be needed, then the electric car may be an important contender in fulfilling our long-range transportation needs.

We believe that governmental backing could foreshorten the time required for developing electric propulsion technology to the stage of commercial feasibility. Furthermore, the government needs to pave the way for electric vehicles through enabling legislation as well as administrative action if electrics are to be permitted to enter into an existing vehicle population.

GM Alternative Power Plant Research and Development

For many years, General Motors has committed substantial resources to developing alternatives to the current automobile engine. We are committing substantial effort and resources to alternate fuel engines, small diesels, gas turbines, stratified charge engines and others.(1-11) Our total alternative power source research and engineering expenditures for 1975 are expected to be about 50 million dollars. These expenditures since 1967 are detailed in Attachment A.

Our efforts also include a great deal of work on propulsion systems with potential for the longer term future. Electric vehicles, of course, are in that category. At our Research Laboratories alone, about 30 people are working intensively on advanced propulsion batteries and fuel cells. We are carrying on basic research on electrode mechanisms and the electrode processes that lead to deterioration upon cycling. We are also carrying out research on materials for electrodes, separators and electrolytes, to minimize battery weight while achieving adequate life. Others in our Electrical Engineering Department at the General Motors Research Laboratories are looking at optimized electric drive systems, including traction motors, controls and electronics needed with these advanced batteries.

General Motors is also concerning itself with advanced battery design and manufacturing technology and with the projected costs for making these advanced battery systems. Engineers at our Engineering Staff and at our Research Laboratories are carrying out analytical studies to determine the levels of battery technology required before vehicles of various sizes, weights, ranges and performance capabilities can be considered. We feel that we will be prepared on the engineering and manufacturing details when advanced energy storage devices become feasible for production vehicles.

GM Electric Car Experience

Over the past decade, we have built and tested a series of electric and hybrid vehicles using the most advanced state-of-the-art components, to develop and optimize motor and control systems, and to gain actual operating experience. Characteristics of these cars are documented in Attachment B.

We have also purchased or test driven electric vehicles manufactured by other companies. Even though we had high expectations with respect to these vehicles, the results were frustratingly disappointing.

One simple and inexorable fact kept bringing us back to reality with every fresh look. Existing batteries, including the most energetic batteries commercially available, couldn't begin to do an effective job of moving people in comparison with gasoline.

The best lead-acid batteries available today with appropriate cycle life for propulsion power in passenger electric cars deliver only 20 - 30 watt-hours of electrical energy per kilogram, depending on the application. Although the peak efficiency from battery to wheels (motor, controls and driveline) can be as high as 85%, it will be no greater than 60% in stop-and-go traffic in city driving. Therefore, the lead acid batteries deliver only 12 to 18 watt hours of energy per kilogram at the wheels.

In contrast, gasoline has an energy density of 13,200 watt-hours per kilogram. Even if a conversion efficiency from the gas tank to the wheels for city driving, were assumed to be as low as 10%*, it would still deliver 1,300 watt-hours per kilogram at the wheels or about two orders of magnitude greater than for the lead-acid batteries. Even the best batteries envisioned today, which may be commercially available in the period around 1990 to 2000, will have only a 6- to 8-fold improvement in energy density over lead acid.

To place it in proper perspective, for the same work done at the wheels as by 20 gallons of gasoline (58 kilograms) in an internal combustion engine vehicle, one would require about 5,000 kilograms of lead acid batteries or 600-700 kilograms of the best projected batteries. It becomes obvious why electric cars will continue to be much heavier than their internal combustion engine counterparts designed for the same mission.

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*Average tested efficiency (from gas tank to wheels) for all 1975 cars for EPA urban driving cycle -- by EPA laboratories, Ann Arbor, Michigan, 11.5%.

Because of this battery limitation, electric vehicles are unable to match the performance and range of gasoline powered vehicles. They suffer from greater weight, both the battery weight and necessary added vehicle structure, and this weight penalty demands more propulsion energy. In addition, the original cost is high, and, when amortization is considered, the operating cost also is high.

We have learned a great deal from our research on electric vehicles. However, the typical electric car of today is substantially underpowered for safe driving in existing traffic situations. Because of this, the driver's natural inclination would be to drive it "full-throttle" to try to get up to the maximum vehicle speed capability, which is usually at or below urban thoroughfare traffic speed. And when he finally gets to that speed, he must keep his "foot to the floor" to maintain that speed. Because he is now draining the batteries at the "maximum rate," his operating range falls well below his expectation. After relatively few miles, his ability to maintain speed, or to accelerate again to traffic speed from a stopped position, begins to diminish. As the battery pack ages, vehicle performance falls off; as the battery pack loses charge, performance diminishes. In cold weather, both range and performance decrease.

In designing batteries for electric vehicles, there are tradeoffs among specific power, which determines vehicle performance, specific energy, which affects vehicle range, and battery life, which influences vehicle operating cost. The Electrovair II, shown on page 1, Attachment B, was built using silver-zinc batteries as a power source. It had good performance -- it nearly matched the gasoline engine Corvair performance -- and this made it effective in mixing with regular traffic. But this performance was attained at serious sacrifice of battery life and range capability.

Silver-zinc batteries would be impractical for wide transportation use because of high initial cost. The batteries in Electrovair II contained about $10,000 worth of silver at today's market prices. But they were chosen for the experiment because the technology for building them was available. In addition, they matched the performance capabilities expected from some of the advanced batteries now being developed for use beyond the next decade.

Our 512 electric vehicle, shown in Attachment B, used commercially available batteries, had a top speed capability of only 30-45 miles per hour and could not safely mix with existing traffic.

Incidentally, neither of the two cars would come close to meeting current Federal Motor Vehicle Safety Standards. If they were redesigned to conform to these standards, the added weight would further degrade their performance, range and operating economy. When vehicle weight is added to meet safety and/or performance requirements, additional weight must be added to the chassis, drivetrain, suspension and other components to maintain vehicle performance and structural integrity.

Have we given up on electric propulsion? No, indeed! But for the present we feel that building more electric vehicles is a waste of resources. The real problem -- and really the only technological roadblock to electric personal transportation -- is the battery system itself. No technological breakthroughs are required for devising electric drive systems, motors, controls, choppers, inverters or other circuitry, although substantial engineering effort would be required to tailor these electrical components to individual vehicles. There are many ways available to design and build adequate hardware to fit specific vehicle needs.

We are now concentrating our efforts on basic electrochemical research and on engineering development of advanced batteries. Zinc-nickel oxide, sodium-sulfur and lithium-sulfur currently offer at least some promise of providing a reasonable combination of specific power, specific energy, durability and cost for future electric vehicles. We have looked at other systems as well -- lithium-chlorine, zinc-air and zinc-chlorine, for example, and have considered these too costly or too impractical.

"Findings" of 5470

Mr. Chairman, Section 2 of H.R. 5470, the "findings" which presumably form the basis for this proposed legislation, contains a number of statements which are incomplete or inaccurate. Thus, they could provide erroneous conclusions about prevailing conditions and faulty assumptions on which to base legislative action. I would like to make some comments about these findings which, I hope, will contribute to a more balanced perspective of the role of battery-powered vehicles:

Finding #1 "travel patterns of commercial and private vehicles in urban areas are weighted heavily toward short and predictable trips well within the capability of electric vehicles of current design;"

In a restricted transportation role, the battery-electric vehicle already has a place in our transportation system. It currently serves in golf carts, lift trucks and on-site people movers. Commercial urban delivery vehicles and buses for low speed, short range service with frequent stops are available and seem to perform satisfactorily in this specialized use. Downtown shoppers, commuters and "erranders" as well appear technically feasible today with lead-acid battery technology. This is not to say, however, that present travel patterns in urban areas are within the capability of electric vehicles of current design. It must be remembered that when large numbers of small personal transportation vehicles are contemplated for use on streets as opposed to golf courses, factories and restricted commercial service, federal auto safety requirements would have to be met, and this will adversely affect their size, weight and cost. There are many other unanswered questions about the safety hazards involved in mixing extremely small, lightweight, low performance vehicles with today's conventional cars and trucks on urban streets and freeways.

Finding #2 "our balance of payments and our economic stability are threatened by the need to import oil for the production of liquid fuel for gasoline-powered vehicles"

Automobiles account for only about 13% of total energy use, and less than 30% of petroleum use. In 1974, we consumed 1,370 million barrels of oil for automobiles and 485 million barrels for electric power generation. We imported 2,240 million barrels. If all automobiles were to be removed from the streets, we would still need to import oil for other uses. If additional electric power required for charging the electric car batteries were to be generated from oil, rather than nuclear power or coal, any advantage in reducing oil imports would be substantially reduced.

The question of converting a substantial portion of our transportation system to electric power cannot be answered in isolation from other energy policy considerations. Any appreciable impact on petroleum imports from introducing electric vehicles can be achieved only gradually and in the long-range future -- if it is found to be desirable as the nation's energy policies are defined.

Finding #3 "the shortage of fuel for gasoline-powered vehicles will continue indefinitely;"

It is inappropriate to single out gasoline-powered vehicles in this context so long as there are other uses of petroleum for which substitutes may be more readily available. This statement could just as plausibly be amended to read: "The shortage of fuel for gasoline-powered vehicles will continue indefinitely so long as major quantities of petroleum are used to generate electric power or for large industrial and commercial boiler fuel." The existence or continuation of any gasoline "shortage" involves considerations and definitions of present and future energy policy.

Finding #5 "the strain on individuals' budgets inflicted by liquid fuel prices mandates the development of an alternative source of propulsion wherever possible;"

This statement implies that the cost per mile of electric vehicle travel will be less than the cost per mile with gasoline. Our engineering studies indicate that this assumption may not be true. Because an electric vehicle is considerably heavier than its gasoline powered counterpart of equivalent performance, it requires about 40% more energy at the wheels. In addition, the cost to the consumer of energy in the form of electricity is much higher than the cost of energy as gasoline at current prices. Attachment C, Table I, for example, indicates that one million BTU's of electricity in the Detroit area in February, 1975, cost the consumer 1.88 times as much as one million BTU's in gasoline.

However, the onboard energy conversion efficiency of electric vehicles is over twice (2.3X) that of gasoline powered vehicles. The net result is that the energy cost to the operator of a small electric shopper would be about 15% more than the cost of gasoline for a similar internal combustion engined shopper (1.4 X 1.88/2.3 = 1.15). Attachment D explains these issues in more detail.

Finding #7 "stationary sources of pollutants are potentially easier to control than moving vehicles, making it environmentally desirable for transportation systems to be powered from central sources;"

Electric utilities that burn fossil fuels do emit pollutants -- both oxides of nitrogen and sulfur oxides. Coal burning power plants emit these two pollutants at much higher levels.(12) According to EPA data,(13) sulfur oxides on a pound for pound basis are considered more injurious to health than conventional auto emissions.

Thus, while control methodology may be easier to apply, actual ambient air quality standards would probably be more difficult to achieve if electric cars supplanted the existing fleet of cars. Attachment E shows a comparison of the grams per mile pollution from gasoline-powered cars meeting 1976 and 1978 standards with electric cars using power from coal-burning power plants meeting EPA standards. On a health weighted equivalent basis, using the primary air quality standards established by EPA,(13) the electric car would result in from 2.3 to 12 times as much pollution in the air from power plants as from the exhaust of the gasoline-powered car. Of course it must be recognized that automobile exhaust is emitted close to the ground and largely in urban areas, while the effect of emissions from electric power plants depends largely on their location with respect to urban areas.

A report prepared by William Hamilton under contract to EPA, entitled "Impacts of Electric Car Use In St. Louis, Philadelphia, and Los Angeles," shows that an 80% electric car population in these cities in 1990 would have little effect in reducing hydrocarbon or CO levels, the principal automotive-related pollutants. Added electric power generation, however, would seriously increase sulfur oxide levels. This report has been included with our statement as Attachment F.

Finding #9 "electric-powered vehicles do not emit any significant pollutants and are far less noisy than conventional automobiles and trucks;"

While we do not now know of significant pollutants emitted by battery-powered vehicles, some of the batteries being considered for future applications use sulfur, chlorine, nickle, zinc, lithium cadmium, sodium and other substances which may be introduced into the environment. The potential for environmental risk from these substances should not be dismissed.

Finding #11 "because electric vehicles use little or no energy when stopped in urban traffic, they permit the conservation of energy currently wasted by conventional automobiles and trucks;"

This statement is not incorrect; but it is, to some extent, misleading. Energy would be required for heating in cold weather, even when the vehicle is stopped at traffic lights and for vehicle lighting, signalling, defrosting and other essential uses. These factors tend to reduce the miles that can be driven on a unit of fuel. It is appropriate, however, to compare the efficiency of electrics and conventional cars on an urban driving cycle. Comparisons in this testimony have been made on the basis of the EPA urban cycle in which 18% of the time is spent idling.

Finding #12 "the power demands of electric vehicles would promote energy conservation by loading utilities in off-peak late night hours, permitting more efficient use of plant capacity;"

Because electric cars are expected to continue to have limited range/performance characteristics, they will be relegated to short-trip shopping and commuter use. Most errands of this type are carried out during daytime hours, and the tendency would be to put them "on charge" as soon as the mission is completed, to make sure the vehicle will be ready for the next demand. If they are to be used for commuting, charging probably will be accomplished during the working day. Thus, while some battery charging would be done at night during off-peak hours (possibly encouraged by changes in rate structures favoring off-peak use), a great deal of this additional load would be likely to come during daylight and "peak" hours.

Finding #13 "the depressed state of the current automobile industry would be alleviated by the introduction of new technologies more closely matching consumer needs;"

This statement implies that technology exists today to provide electric powered vehicles that "more closely match consumer needs" than the vehicles presently available, and if those electric vehicles were made available, they would sell in large quantities.

We believe electric vehicles may play an increasing future role in our transportation system. But there is no basis for the implication that there is an existing market for electric cars of such magnitude as to alleviate "the depressed state of the current automobile industry." Considering the dynamic nature of the American economy, it is inconceivable that if a substantial opportunity to market electric cars existed, it would long be overlooked by the automobile industry or by other companies who could provide electric car entries.

Commercial Feasibility

One stated purpose of H.R. 5470 is to "demonstrate the commercial feasibility of electric vehicles." Implicit in the term "commercial feasibility" is a demonstration of the salability of the product. Does the product fulfill people's wants and needs so that they will buy it? Surely, government subsidies for private individuals to encourage use of electric vehicles and government requirements that they be used by the Postal Service and the General Services Administration hardly demonstrate that they are desirable, salable products on their own merits.

The Role of the Federal Government in Electric Propulsion R & D

General Motors does not believe that much can be gained at this time by subsidizing the sale of electric vehicles. The capability of electric vehicles with state-of-the-art battery technology is well known. Until better batteries are developed, those capabilities are not likely to be improved drastically.

We believe the production, at this time, of a significant number of electric vehicles would:

(a) be costly and without real benefit;

(b) be uninformative regarding the real problem -- the batteries;

(c) mix a low performance vehicle population with the current automotive population; and

(d) not move us close to energy self-sufficiency in a reasonable time, since some petroleum conserved in the refining of less gasoline probably would merely be consumed in extra power plant generation, especially for peaking power.

The 352 electric vehicles currently being readied for the Postal Service should comprise an adequate sample to demonstrate capability and determine performance. Presumably these new vehicles employ the latest in commerical battery technology and will provide a test in service best suited to this type of vehicle.

We question the need for the government to subsidize products for sale in a competitive market. Private industry is better equipped and sufficiently motivated to respond to that phase of the problem. There is a role for government to play in supporting research and development on advanced battery and fuel cell technology where the real bottlenecks to commercial feasibility exist.

Electrode processes, electrode catalysis, development of better battery material and improved cell durability are areas which now represent critical bottlenecks in the industry's efforts on battery-powered cars. Government support of research in these areas would supplement rather than duplicate the efforts of industry and thus make real contributions to progress.

The second area for useful government effort concerning the electric car is directed toward energy and traffic management considerations in which the government should and must carry the major responsibilities. Some of these issues and value judgments are beyond the appropriate role of business.

It is important to understand the social, economic and environmental impact of electric vehicles on a nation where a shortage of electric power capacity is threatened. Studies of urban traffic problems and the effects of added congestion resulting from slower electric vehicles mixing with other vehicles are both necessary and desirable.

It would be advisable for Congress to have available a better understanding of a feasible and appropriate role for electric cars in the nation's energy policy before committing large amounts of public funds to promote widespread use of electric vehicles. When nuclear power and coal assume the dominant role in generating electrical power, then the electric car could begin to assume a more effective role in our nation's energy and transportation systems.

As higher performance batteries with greater durability, power and energy storage capability at reasonable cost are developed, combined with increased electric power generation capacity based on nuclear power, battery-powered electric cars should become more competitive with alternates. When the economics of electric cars become more favorable, there will be no need for the expenditure of public funds to promote them. Our competitive system will ensure that the products are provided as the commercial opportunity develops.

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REFERENCES

1. E. M. Estes, "Alternative Power Plants for Automotive Purposes," The Institution of Mechanical Engineers, James Clayton Lecture, Proceedings 1972, v. 186 11/72.

2. W. G. Agnew, "Automotive Powerplant Research," Statement presented to The Senate Subcommittee on the Environment and The Senate Subcommittee on Science, Technology and Commerce, Washington, D.C., May 14, 1973.

3. E. S. Starkman, "Research on Ground Propulsion Systems," Statement presented to the Subcommittee on Space Science and Applications of the House Committee on Science and Astronautics, Washington, D.C., June 12, 1974.

4. "GM Progress of Power" Background Information prepared by Technical Information Department, Research Laboratories, General Motors Corporation, May 1969.

5. "1974 General Motors Report on Programs of Public Interest," prepared by Public Relations Staff, General Motors Corporation, April 1975.

6. "General Motors Corporation 1974 Report on Progress in Areas of Public Concern," prepared by Public Relations Staff, General Motors Corporation, February 7, 1974.

7. "1973 Report on Progress in Areas of Public Concern," prepared by Public Relations Staff, General Motors Corporation, February 8, 1973.

8. "1972 Report on Progress in Areas of Public Concern," prepared by Public Relations Staff, General Motors Corporation, February 10, 1972.

9. (1971) "Progress in Areas of Public Concern," prepared by Public Relations Staff, General Motors Corporation, February, 1971.

10. "General Motors Progress Toward Achieving the 1978 Automotive Emission Standard for Oxides of Nitrogen," submitted to U.S. Environmental Protection Agency Mobile Source Air Pollution, Washington, D.C., March 3, 1975.

11. "General Motors Request for Suspension of 1977 Federal Emissions Standards," submitted to U.S. Environmental Protection Agency, January 10, 1975.

12. News Report, National Academy of Sciences, National Research Council National Academy of Engineering, XXV No. 3, March 1975.

13. Federal Register, 36, 8186 and 15486 (1971).

Attachment A

General Motors Corporation
Automotive Emission Control Expenditures
Total Research & Engineering
1967 Through 1975
Calendar Year Basis

($000's)

Year	Current Gasoline Piston Engines	Alternate Power Sources	Total
	$	$	$
1967	14,565	3,511	18,076
1968	18,010	7,977	25,987
1969	28,033	15,135	43,168
1970	43,978	19,098	63,076
1971	69,337	30,048	99,385
1972	81,536	32,952	114,488
1973	97,604	49,464	147,068
1974	87,626	49,296	136,922
Sub-Total	440,689	207,481	648,170
1975*	91,749	50,431	142,180
Total	532,438	257,912	790,350

*Estimated

Note: Fuel economy research and development expenditures are included in the above numbers, but not segregated since General Motors records are not kept in this fashion.

GM

"EXPERIMENTAL" ELECTRIC AND ELECTRIC HYBRID VEHICLES

ELECTROVAIR I AND II

(Engineering Staff)

Program Started - January 1964:

I. Operational - November 1964 (1964 Corvair)

II. Shown to public - October 1966; results presented January 1967 - SAE 670175; refined motor controls concepts. (1966 Corvair)

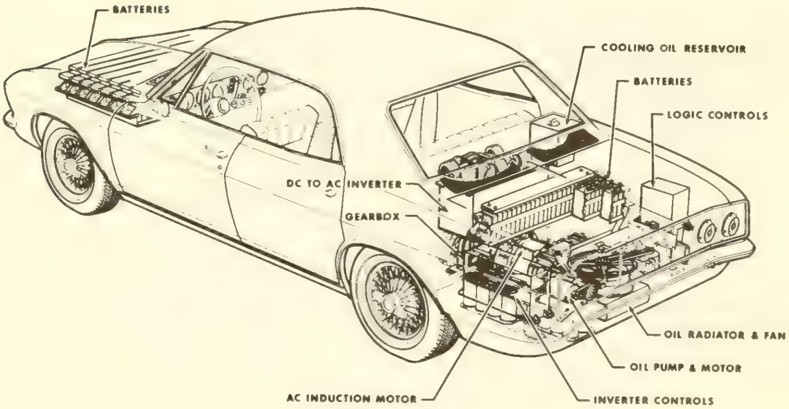
Power Train:

Battery Pack - Silver-zinc - highest available energy storage and peak power output/lb. (Batteries purchased from Yardney Electric Corp.) Costly and limited cycle life; voltage - 530 V; 680 lb.

Motor - AC induction - 100 HP - 13,000 rpm - 130 lb.

Controls - 18 SCR provides variable voltage and frequency.

Performance:	Electrovair II	Corvair
Weight	3400 lb	2600 lb
0-60 mph	16 sec	16 sec
Top speed	80 mph	86 mph
Range	40-80 miles	250-300 miles
Power Train Weight	1230 lb	610 lb



ELECTROVAIR I AND II

(Engineering Staff)

Features:	ADVANTAGES	DISADVANTAGES
	Good power density	Low range
	No exhaust emission	Very high cost
	Quiet operation	Long recharge time
		Short life

Conclusion: Program stopped January 1967. Further technological advances needed in electric power train - particularly in battery area.

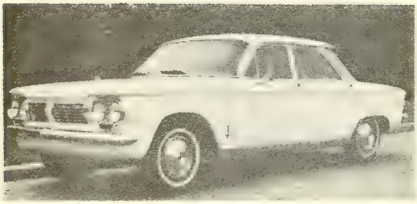


Figure 1 - Electrovair I built on a 1964 Corvair body and chassis.

Figure 2 - Electrovair II built on a 1966 Corvair body and chassis.

"Electrovair - A Battery Electric Car"
E. A. Rishavy, W. D. Bond, T. A. Zechin, GM Engineering Staff.

SAE Paper 670175
Presented at SAE Automotive Engineering Congress and Exposition, Detroit, Michigan, January 9-13, 1967.

ELECTROVAN

(Engineering Staff)

Program Started - August 1964:

Shown October 1966; results presented January 1967 - SAE 670176 and 670181.

Power Train:

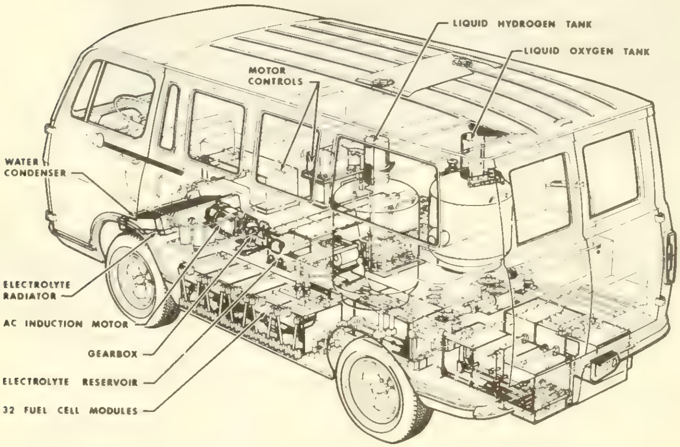
Fuel Cell - H_2-O_2 (largest H_2-O_2 fuel cell of its kind in world)	Developed and built by Union Carbide Corp. Fuel cell discussions were concluded with Allis Chalmers, General Electric, Pratt and Whitney, Esso and Union Carbide. Pratt and Whitney and Union Carbide were given phase 1 contracts to build 1 KW_e units. Union Carbide supplied fuel cell hardware for Electrovan. 32 modules - 1 kW/module continuous 42#/each (dry); 5 kW/module peak; voltage - 520 V.
Motor and Controls	Very similar to Electrovair II.

Test Bed:

1966 GMC Handivan

Performance:

Total Weight - 7100 lb
Power Train Weight - 3930 lb
Top Speed - 70 mph
0-60 mph - 30 sec
Range - 150 miles



ELECTROVAN

(Engineering Staff)

Features:

ADVANTAGES	DISADVANTAGES
High efficiency	High weight
Good range	Very high cost
Quick refuel	Low power/weight
No exhaust emission	Complex
Quiet operation	Safety
	Short life

Conclusion: Program stopped January 1967. Further significant technological advances needed in fuel cell areas of economics, power per unit of weight.

"Electrovan - A Fuel Cell Powered Vehicle"
C. Marks, E. A. Rishavy, F. A. Wyczalek, GM Engineering Staff.

SAE Paper 670176
Presented at SAE Automotive Engineering Congress and Exposition,
Detroit, Michigan, January 9-13, 1967.

512 URBAN CAR

(Engineering Staff)

Program Started - December 1966

Shown - May 1969; results presented May 1969 - SAE 690461.

Power Train:

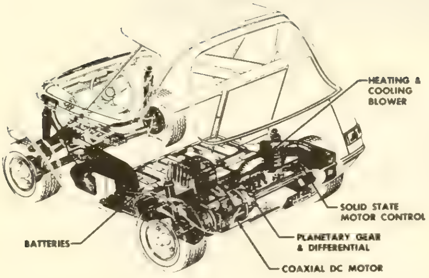
Lead-Acid Battery - Deep discharge, lightweight (Delco-Remy) 330 lb; 84 V.

Motor and Controls - DC series (Delco-Remy) - 54 lb 8-1/2 HP at 4000 rpm continuous.

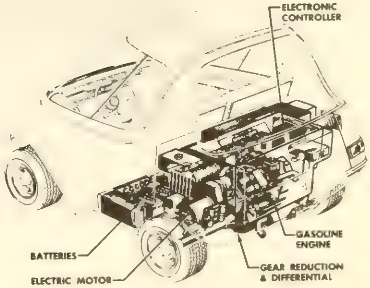
Solid state controller (Delco-Remy)

Performance:

Weight	1250 lb
Power Train Weight	575 lb
Top Speed	45 mph
0-30 mph	12 sec
Range at 30 mph	47 miles



ELECTRIC CAR



HYBRID CAR

512 URBAN CAR

(Engineering Staff)

Features:

ADVANTAGES	DISADVANTAGES
Special purpose vehicle	Low range
No exhaust emissions	High weight
Very small size	Cannot mix with conventional traffic patterns
Minimize - traffic problem	
- parking problem	
Quiet operation	

Conclusion: Program stopped April 1969. Further improvements in electric power train technology needed to satisfy urban car performance and economic needs.

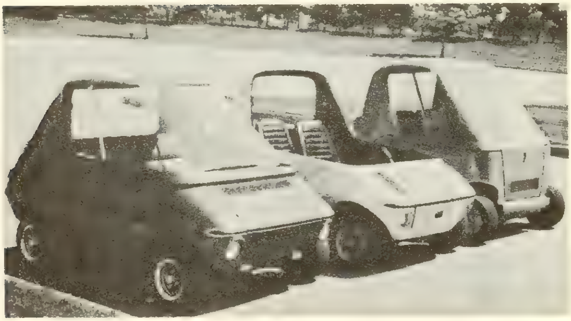


Figure 3 - The electric powerplant is installed in the final body configuration, the gasoline engine in a sport roadster version, and the hybrid in an early test bed vehicle.

"Special Purpose Urban Cars"
J. J. Gumbleton, D. L. Frank, S. L. Genslak, A. G. Lucas, GM Engineering Staff.

SAE Paper 690461 - Presented at SAE Mid-Year Meeting, Chicago, Illinois, May 19-23, 1969.

XEP-1A

(GM Research)

Program Started - 1968: Operational - April 1970. Shown - June 1970.
Results presented January 1971--SAE 710234 and 719014.

Power Train:

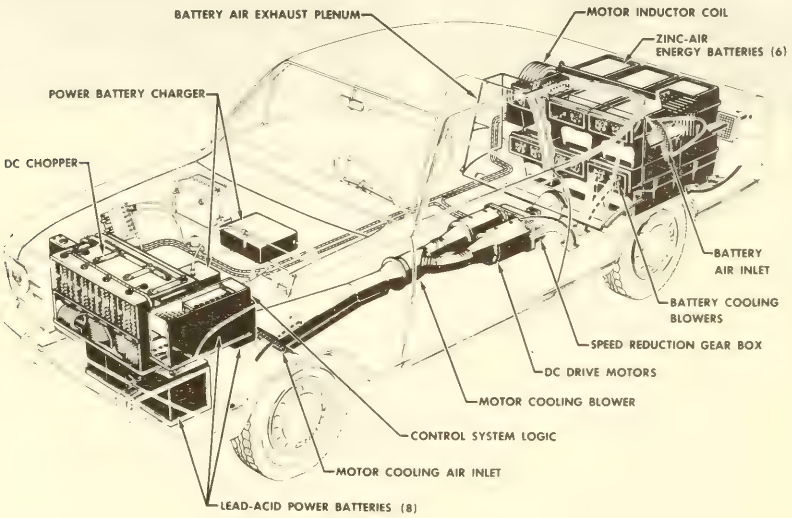
Powerplant - (Dual Battery)
Zinc-Air (GMR)* - 20 kW; 27 kWh; 648 lb.
Provides the energy and power for cruising to 60 mph; recharges the Pb-acid battery pack.
Lead-Acid (Delco-Remy-GMR) - 20 kW; 1.6 kWh; 250 lb.
Provides additional power for acceleration.

Motor - 2 - dc series motor (Delco-Remy)
14 HP continuous; 18.5 HP peak.

Controls - Solid state chopper and logic (GMR)

*Zinc-Air discussions were conducted with Leesona Moos Laboratories. Leesona Moos proposed to develop and build the zinc-air battery, but GMR decided to do the job in-house and gain important experience.

Performance:	XEP-1A (1968 Opel Kadette)	1968 Opel Kadette
Curb Weight -	2957 lb	1720 lb
Test Weight -	3404 lb	
Power Train Weight -	1575 lb	425 lb
Battery Weight -	904 lb	
0-30 mph	8.5 sec	
Range: 30 mph	155 miles	
55 mph	90 miles	



XEP-1A

(GM Research)

Features:	ADVANTAGES	DISADVANTAGES
	Satisfactory urban range	Heavy
	No exhaust emissions	Cost premium
	Quiet operation	Long recharge time needed
	Potential promising Zn-air battery economics	Short life

Conclusion: Program stopped January 1971. Efforts directed toward research activity to evolve an electrically rechargeable zinc-air battery.

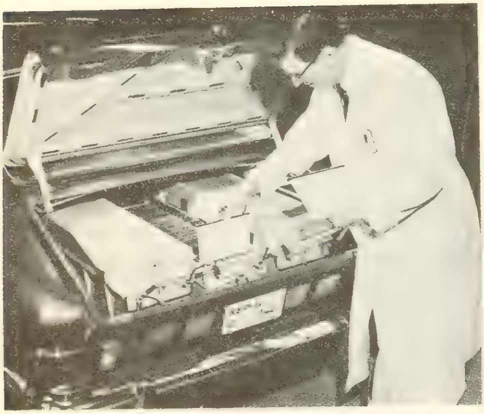


Figure 4 - Rear view showing the installation of the six zinc-air modules in the trunk of the vehicle.

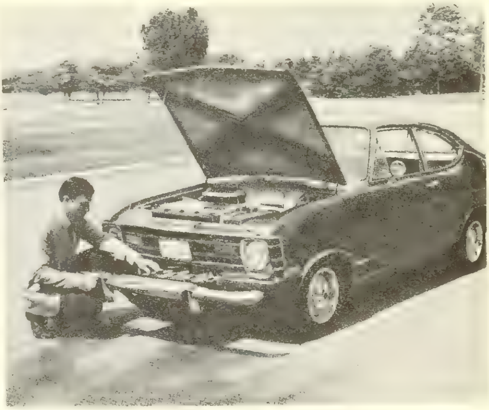


Figure 3 - Front view showing four of the eight lead-acid power batteries on a pull-out tray attached to the front bumper. Electronic components are visible behind the grille.

WHISPERYET

(GMC Truck and Coach)

Program Started - mid-1968:

Shown November 1969; results presented to DOT personnel.

Power Train:

Series Hybrid -

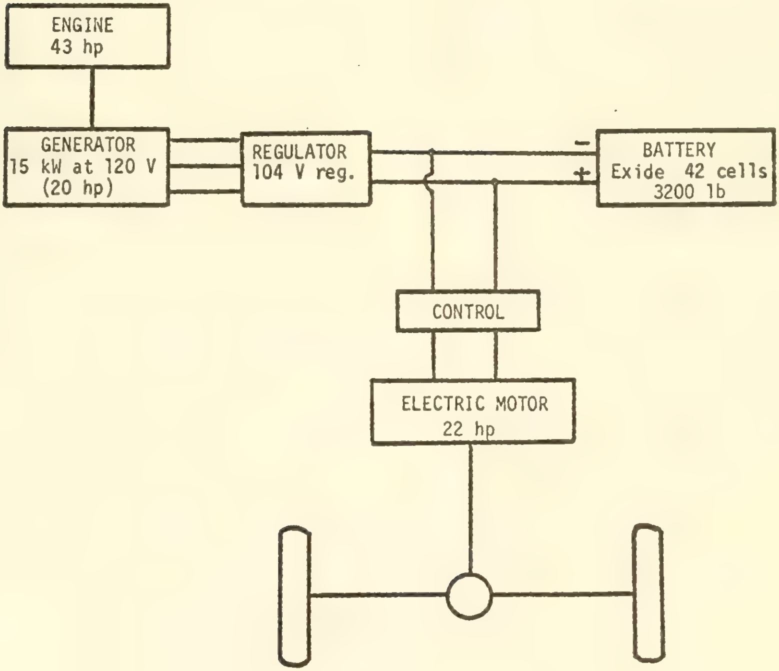
- Kohler engine-generator - 15 kW at 120 V
- Exide batteries - 3200 lb
- Electric Motor - DC traction - 20 HP - 80 V. (Purchased from Reliance Electric Company.)

Test Bed:

City Bus - GVW = ~ 20,000 lb; 25-30 passengers.

Performance:

Top Speed - 27 mph.



WHISPERYET

(GMC Truck and Coach)

Conclusion:	Program stopped summer 1970; lack of promise.

General Motors
Research Laboratories

GM STIR-LEC II

A STIRLING-ELECTRIC HYBRID CAR

Stir-Lec II is a second-generation hybrid automobile combining a Stirling external combustion engine with an electric drive system. It was developed by General Motors Research Laboratories as a test vehicle to explore the use of a low emission engine and an electric drive system in a small car.

The hybrid arrangement allows the use of a very small engine (eight horsepower) to provide electrical power for moderate constant-speed driving, with reserve power stored in a bank of batteries.

General Features

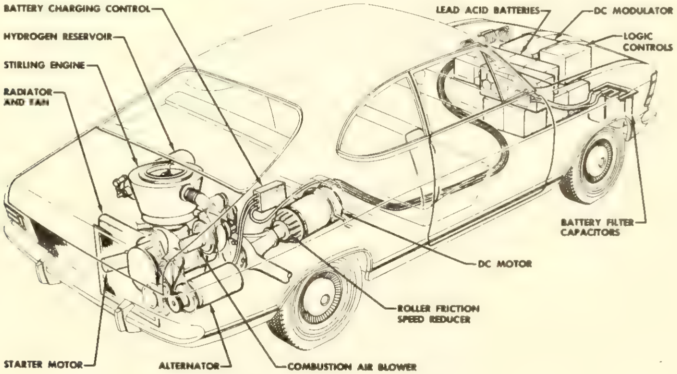
The first experimental vehicle of this family, Stir-Lec I, was introduced to the public in May 1968. The second, Stir-Lec II, features a more efficient electric drive system which provides the same power with simpler, more compact electronics. It is the latest result of an extensive development program on high-performance electric drive systems, coupled with over a decade of Stirling engine development.

Features of the Stirling engine include low exhaust emissions (considerably below both present and proposed government limits), quiet operation, and high efficiency. The electric system provides high peak power for rapid vehicle acceleration, the flexibility and performance characteristics of an electrical transmission, and zero exhaust emissions when the vehicle operates on batteries alone.

In Stir-Lec II, the small Stirling engine drives an alternator to charge the batteries. The battery output is electronically modulated to provide the necessary power variations for motor speed control. A 20-hp dc motor drives the vehicle through a GMR-developed roller friction speed reducer and the standard differential. This differs from Stir-Lec I which used an ac motor and speed reduction gears. In this small vehicle (a modified Opel Kadett) the advantages of simpler, less bulky dc system electronics outweigh the advantages of a smaller, lighter ac motor. In larger vehicles -- where a powerplant of more than 30-40 hp is required -- the large size and weight of the dc motor make the ac system more desirable. The GMR Electric Propulsion Department continues development of both systems for a variety of applications.

Low Emissions

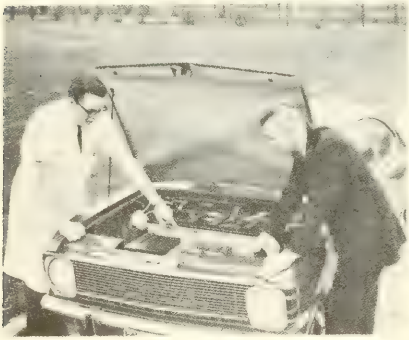
In the Stir-Lec installations, the eight horsepower single-cylinder Stirling engine runs at constant speed. Although its main function is



charging the batteries, it also provides hot water for the car's heater. A diesel fuel burner supplies the required heat to the Stirling external combustion engine. Combustion characteristics are excellent. The engine package emits virtually no odor and very low amounts of carbon monoxide and smog-forming hydrocarbons. Carbon monoxide is typically about 0.3 grams per mile (gpm); proposed 1970 federal standards limit such emission to 23 gpm. Exhaust hydrocarbons are typically about 0.006 gpm; the proposed federal hydrocarbon limit is 2.3 gpm. The emission of oxides of nitrogen is about one gpm. The Stirling engine also is significantly quieter than conventional engines. This engine is a modified version of the Stirling developed by the GMR Mechanical Development Department for use in a silent portable Army generator (Ground Power Unit).

R&D . . . Test Results

The Stir-Lec cars were designed to explore the characteristics of this type of powerplant and drive system in a small standard car. The space required by the system (it uses all the engine compartment and trunk space), the added weight, and high cost all make this hybrid design commercially impractical at this time. However, Stir-Lec II does serve as a valuable test bed for continuing research and development.



Stir-Lec II features compact solid state chopper and logic controls for dc drive system.

Stir-Lec II has a top speed capability of about 60 mph, however the nominal operating speed is 30 mph. At 30, on a level road, the electric drive system draws energy from the batteries at about the same rate that the Stirling engine charges them. Thus the batteries essentially "float" on the system, and the Stirling supplies the required energy. At higher speeds, or for other temporary additional power needs (such as acceleration or hill climbing), the motor draws some of the stored energy from the batteries. The batteries can then be recharged during lighter-load operation.

The car also can operate with no emissions, with the Stirling engine shut down and the vehicle running only on the batteries. The emission-free range is about 30 miles.

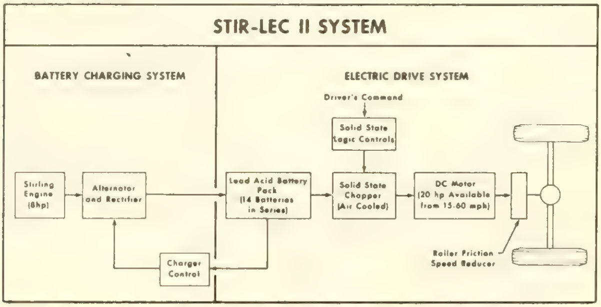
Initial performance data for Stir-Lec II looks like this:

Acceleration 0 to 30 mph, in 8.5 seconds.

Top speed, 60 mph.

Range, 25 miles at 30 mph on batteries alone.
150 miles at 30 mph with the charging system running (limited only by capacity of 5 gal. fuel tank).

The weight of the vehicle, including two occupants, is about 3250 pounds.


STIR-LEC II SYSTEM
BATTERY CHARGING SYSTEM
ELECTRIC DRIVE SYSTEM
Driver's Command
Solid State Logic Controls
Stirling Engine (8hp)
Alternator and Rectifier
Lead Acid Battery Pack (14 Batteries in Series)
Solid State Chopper (Air Cooled)
DC Motor (20 hp Available from 15-60 mph)
Charger Control
Roller Friction Speed Reducer

Prepared by TECHNICAL INFORMATION DEPARTMENT
GM Research Laboratories, Warren, Michigan 48090
May 1969

TABLE I

CONSUMER ENERGY COSTS, DETROIT AREA, FEBRUARY 1975

	($ Per Million Btu's)
Natural Gas	1.15*
Gasoline	4.40**
Electricity	8.26***

*Monthly service charge of $3 per customer not included.

**At 55 cents per gallon.

***Monthly service charge of $2.40 per customer not included.

TABLE II

ELECTRIC UTILITIES

GENERATION BY ENERGY SOURCE (PERCENT)

			U.S.	New England	West South Central	East South Central
	1973[1]	1974[2]	1974[3]			
			Percent Fossil Fuel Only			
Coal	45.8	45.5	57.1	13.1	3.2	92.5
Oil	16.8	15.2	20.6	85.4	6.8	4.1
Gas	18.2	17.7	22.3	15	90.1	3.4
Fossil Total			100	100	100	100
Hydro	14.7	16				
Nuclear	4.5	5.6				
	100	100				

[1] Edison Electric Institute "Statistical Yearbook for 1973"

[2] Monthly Energy Review FEA, March 1975

[3] FPC News, March 28, 1975

RESEARCH PUBLICATION ● GMR-1798

ENERGY UTILIZATION COMPARISON OF GASOLINE AND BATTERY-ELECTRIC POWERED URBAN VEHICLES

David C. Sheridan
John J. Bush
William R. Kuziak, Jr.

Power Systems Department

November 15, 1974

RESEARCH LABORATORIES
GENERAL MOTORS CORPORATION · Warren, Michigan

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Research Publication GMR-1798

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ABSTRACT

An analytic study was conducted to compare the efficiency of utilization of the earth's fossil energy resources (petroleum and coal) by battery-electric and gasoline powered special-purpose vehicles. This report presents a brief overview of the study objectives, procedures and findings.

OBJECT

To present a brief review of the energy utilization comparison of gasoline and battery-electric powered urban vehicles.

SUMMARY

Assuming coal is the prime energy source, the energy consumption of a lead-acid battery electric powered 2-passenger shopper vehicle ranges from 25 percent less to about the same as that of a spark ignition engine powered vehicle that has similar performance and carrying capacity. With petroleum as the prime source of energy, the same battery-electric powered vehicle consumes over 40 percent to nearly 90 percent more than a conventionally powered vehicle over a prescribed driving cycle. Increases in desired range, performance or vehicle size beyond that of the shopper increase the electric vehicle energy consumption with respect to the gasoline powered version. These conclusions are based on current level technology. Battery technology advances enabling nickel-zinc cells to be utilized will improve the energy consumption of the electric vehicle with respect to the gasoline powered vehicle by as little as 10 percent in the 40 km range 2-passenger shopper vehicle considered in this study and by as much as 40 percent in the 120 km range, 4-passenger sedan.

DISCUSSION

Introduction

In order to convey the important findings of an urban vehicle energy utilization study a brief overview of the objectives, procedures and findings has been prepared. An important aspect of this study is the basic guidelines set down at its onset. The more important ones are listed below:

1. Current technology supported by experimental data should be utilized to characterize the vehicle-powertrain systems.

2. The vehicles would be smaller and have substantially lower performance levels than those of conventional sub-compact cars.

3. The performance levels and load carrying capacity of the gasoline powered and battery-electric powered vehicles should be identical.

4. Energy consumption and driving range should be determined for operation over an appropriate driving cycle.

Vehicle Definition

Three special purpose vehicles were selected for the study. The curb masses listed below apply to the gasoline powered versions and are based on prototypes built for the General Motors Progress of Power Show of May 1969.

2 passenger shopper - 426 kg
2 passenger commuter - 544 kg
4 passenger sedan - 817 kg

The mass of the electric powered versions was increased to account for the batteries and the additional vehicle structure (compounding effect) required for their support. Although these vehicles do not satisfy Motor Vehicle Safety Standards, changes required to conform to these standards will result in similar mass increases for both the electric and gasoline powered versions.

The performance was determined assuming an additional mass (occupants and cargo) of 136 kg for the shopper and commuter and 204 kg for the sedan.

The performance criteria established for each of the 3 vehicle types are listed in Table I. The performance of a Chevrolet Vega is shown for comparison.

Table I - Vehicle Performance Criteria

Criteria	Shopper	Commuter	Sedan	Vega
Maximum car speed, km/h				
2% grade, 24 km/h headwind	-	72	72	-
0% grade, 0 km/h headwind	72	>97	>97	>125
Distance in 4 seconds, m	15	-	-	23
Distance in 10 seconds, m	-	91	91	122
0-48 km/h time, sec	20	-	-	6
0-72 km/h time, sec	-	30	30	12
5% grade speed, km/h	24	24	24	-
20% grade speed, km/h	>0	>0	>0	-
Electric vehicle range, km	40	80	120	-
Duty cycle, GMPG	Central Business District	Suburban	Suburban	-

Engine size was selected to provide the maximum vehicle speed. A 3 or 4 speed synchromesh transmission was incorporated in both gasoline and battery powered vehicles to give the necessary torque multiplication for acceleration and grade performance. An electric motor could be designed to provide the desired level of vehicle performance at the expense of weight and efficiency. However available motor data dictated the use of the transmission.

Powertrain Definition

The electric motor performance was based on data obtained from a 15 kW series-wound DC motor with a chopper control specially designed for vehicular application. The peak efficiency of this motor and controller was 78 percent. During the course of the study this performance was scaled from the 15 kW level to as low as 7 and as high as 45 kW. In addition, the effect of an increase in overall efficiency of 5 percent which could result from improvements to the electrical components was considered.

The spark-ignition engine (SI) characteristics were based on the measured performance of a 4-cylinder 1.2 liter Opel engine. The maximum output of this engine is about 42 kW. Its output was scaled at the same efficiency level, to as low as 7 kW. Scaling to 21 kW or half the 4 cylinder Opel rating is acceptable, as a 2 cylinder version would provide such performance. Scaling another 67 percent to 7 kW leaves room for considerable debate as to the validity of maintaining the same efficiency level. Therefore, the effect of a 20% increase in part-load fuel consumption was investigated.

The remaining portions of the powertrain including synchromesh transmission, rear axle, clutch, etc., were characterized on the basis of current, experimentally determined information.

An essential consideration for any marketable automobile is the accessory requirements. A minimum load of 250 watts at a vehicle speed of 48 km/h to provide for lighting, ventilation and radio was estimated. The addition of an auxiliary passenger heater would be necessary for the electric powered vehicle and quite possibly for the smallest gasoline powered versions, increasing the total accessory load an order of magnitude to 2500 watts. Optional air conditioning would require about the same amount of power. However, for the purposes of this study the minimum accessory load (250 watts) was used. The electric vehicle accessories were assumed to be a constant load powered by the main battery pack. The gasoline powered vehicle accessories were belt driven in the conventional manner.

The vehicle road load characteristics were determined using coefficients for wind resistance and rolling resistance determined experimentally for a Honda Civic. Vehicle frontal area was assumed to be 1.67 m^2 for the shopper, and 1.86 m^2 for the commuter and the small sedan. The assumption of identical frontal areas does not account for potentially larger values for the electric version due to the large battery volume required. However, the relatively low speed driving cycles being considered in the study justify the assumption.

A critical assumption for the electric vehicle is the amount of added mass required to support the batteries. For the purposes of this study, two compounding factors were considered, 50 percent and 30 percent. In other words, for every 100 kg of battery required an additional 50 kg or 30 kg of structure must be added to the vehicle.

Battery Characterization

The most important component in the electric vehicle system, the battery, is also the most difficult to model. The primary study was carried out using experimentally determined energy-density and power-density characteristics for a Delco-Remy lead-acid battery developed in the late 1960's for an electric vehicle prototype.

The energy available from a battery is dependent on several factors: (1) the rate or rates at which it is discharged, (2) its operating temperature and (3) the age of the battery. The assumptions were made that the battery was new and operating at 294 K (70 F). Also, it was assumed that the amount of energy in kilowatt hours (kW•h) available from the battery for driving cycle operation at various power levels was equal to the energy available from the battery if it had been drained only at the maximum level demanded by the motor. When the available energy was withdrawn, the next vehicle maneuver requiring maximum power would result in the battery terminal voltage dropping below a specified level. The distance travelled by the vehicle prior to this instant was defined as its range.

It is recognized that assuming the quantity of energy available over a duty cycle that demands a range of power levels is identical to the quantity available if it is drawn only at the maximum level of the cycle will result in underestimates of range. However, parallel calculations using measured constant-current voltage-time characteristics to more accurately determine the energy availability produced range increases of only 5 percent. It is also noteworthy that considerable energy is left in the battery, i.e., 40 to 50 percent, at the point where vehicle range is determined by the driving cycle performance demands. If the remaining energy is withdrawn at reduced power levels more range is available.

Another subject concerning the available range of lead-acid battery-powered vehicles is charge recuperation. Left in the open circuit condition for several minutes, the charge level of a battery will rise. Driving habits that result in idle or stop time that is substantially longer than driving time will result in range increases if vehicle cold start effects do not become a significant counteracting influence. The recuperative effects of such idle periods were not considered in this study.

Regenerative braking as a means of increasing vehicle range was not considered in the study. Lead-acid batteries are not aptly suited for high charging rates which would be encountered. Furthermore, it is the concensus of most investigators that a range increase of less than 10 percent would be realized.

The efficiency of charging and discharging the batteries requires some additional assumptions. Charging lead acid batteries to the 110 percent level is recommended to guarantee a full charge. If it is done over an 8 hour period with a charger that varies current linearly with time, calculations indicate that 28 percent more energy must be added than can be withdrawn from a full charge to any charge level. In other words, a charge-discharge efficiency of 78 percent is typical of lead-acid batteries. A charging-device efficiency of 90 percent is anticipated for home-type chargers. The overall charge-discharge efficiency is thus 70 percent.

The study was extended to include nickel-zinc batteries, currently the most advanced batteries practically adaptable to vehicular application. Actual experimental performance was used to model this type battery as well. Energy densities 1 to 3 times greater than that available from the high energy lead-acid battery characterize this particular nickel-zinc cell. The same overall charge-discharge efficiency of 70 percent was used when determining the vehicular energy consumption.

Energy Production and Distribution

To evaluate and compare the utilization of the Earth's prime energy sources by gasoline and battery-electric powered vehicles, the efficiency of producing electricity and gasoline from these prime sources must be considered. Coal and petroleum are the only sources considered in this study even though nuclear fuel is potentially the greatest source of our future energy supply. The magnitude of the radioactive reserves needed for nuclear power generation are not known and a comparison with the utilization of coal or petroleum would be meaningless.

The production and distribution efficiencies of gasoline available at a retail pump and electricity available from an AC outlet in the home, from coal and petroleum as prime sources are illustrated in Fig. 1. These efficiency levels are representative of present-day processes and operations.

Vehicle Energy Utilization

A summary of the energy utilization study is presented in Figures 2 through 5. Figure 2 shows electric-vehicle range in kilometers as a function of mass on the appropriate vehicle driving cycle. Both lead-acid and nickel-zinc batteries are considered. The range for each of the 3 vehicle types is shown as a band. The top of the band represents a 30 percent mass "compounding" effect, the bottom a 50 percent effect. No recuperative effects or operation at performance levels less than those required by the driving cycles were considered.

Equivalent prime-source energy consumption in terms of megajoules per kilometer of driving over the prescribed cycle is plotted as a function of total vehicle mass in kilograms in Figures 3 and 4. The data of Figure 3 assumes petroleum as the prime source, and Figure 4 is based on coal. Energy consumption of the 3 battery-electrics are shown as bands, each increasing with vehicle mass. The top of each band was determined for current electrical component efficiency data. The bottom of each band represents an overall efficiency improvement of 5 percent.

From Figure 2, the vehicle mass corresponding to the desired range available from lead-acid batteries was determined, i.e., 40 km for the shopper; 80 km for commuter and 120 km for the sedan. This vehicle mass "spread" (resulting from the different "compounding" assumptions) is indicated in Figures 3 and 4 as a darkened parallelogram for each vehicle type. The maximum and minimum values defined by these small areas defines the variation in energy consumption of each vehicle type referred to the prime source of energy. The maximum value corresponds to current electrical component efficiency levels and a mass compounding factor of 50 percent. The minimum value represents a 5% increase in electrical component efficiency and a 30% compounding factor.

Also shown in Figures 3 and 4 are the equivalent energy consumptions determined for the gasoline-fueled, spark-ignition-engine versions of the three urban vehicles. These energy consumptions are shown as vertical bands illustrating a possible 20 percent decrease in operating efficiency from the level of the 1.2 liter engine used in the study to that of an engine with 1/2 to 1/6 that displacement. Also spotted on these figures is the energy consumption of three 1974 Chevrolet automobiles, i.e., an 8-cylinder Impala, a 6-cylinder Nova and a 4-cylinder Vega. As a point of reference these values represent measured Suburban driving cycle fuel economies of 10.9, 14.0 and 20.3 miles per gallon.

In Table II below, a comparison is made of the energy consumption of lead-acid battery-electric and gasoline powered vehicles with the same cargo capacity and performance. The maximum ratios represent the assumption of a 50% mass compounding "factor" and currently available powertain efficiency levels for the electric vehicle. Increasing the fuel consumption of the spark ignition engined vehicles 20% to account for the small engine size coupled with the 5 percent electrical component improvement and the lower mass compounding factor of 30 percent for the electric vehicles results in the minimum ratios.

Table II- Energy Consumption Ratio: Lead-Acid EV/SI

	Petroleum	Coal
Shopper	1.88 - 1.42	.97 - .73
Commuter	2.44 - 1.72	1.26 - .89
Sedan	3.41 - 2.22	1.76 - 1.14

Effect of Advanced Battery Application

Assuming nickel-zinc batteries can be used in place of the lead-acid type, the vehicle mass corresponding to the desired range is considerably reduced as indicated by Figure 2. Extrapolating the equivalent energy consumption bands in Figure 3 to sufficiently low levels for each vehicle type, the effect of utilizing these higher energy batteries was determined. These effects are shown in Table III below where the nickel-zinc battery-electric vehicle energy consumption is compared with that of the spark ignition engine powered vehicle.

Table III - Energy Consumption Ratio: Nickel-Zinc EV/SI

	Petroleum	Coal
Shopper	1.65 - 1.28	.85 - .66
Commuter	1.79 - 1.36	.92 - .70
Sedan	2.00 - 1.48	1.03 - .76

In Figure 5, a summary of the calculated energy consumption from both prime sources (coal and petroleum) for the three types of vehicles powered by electricity or gasoline are shown. The ranges of energy consumption values reflect the variation of the mass "compounding" effect and the powertrain efficiency levels assumed in the study.

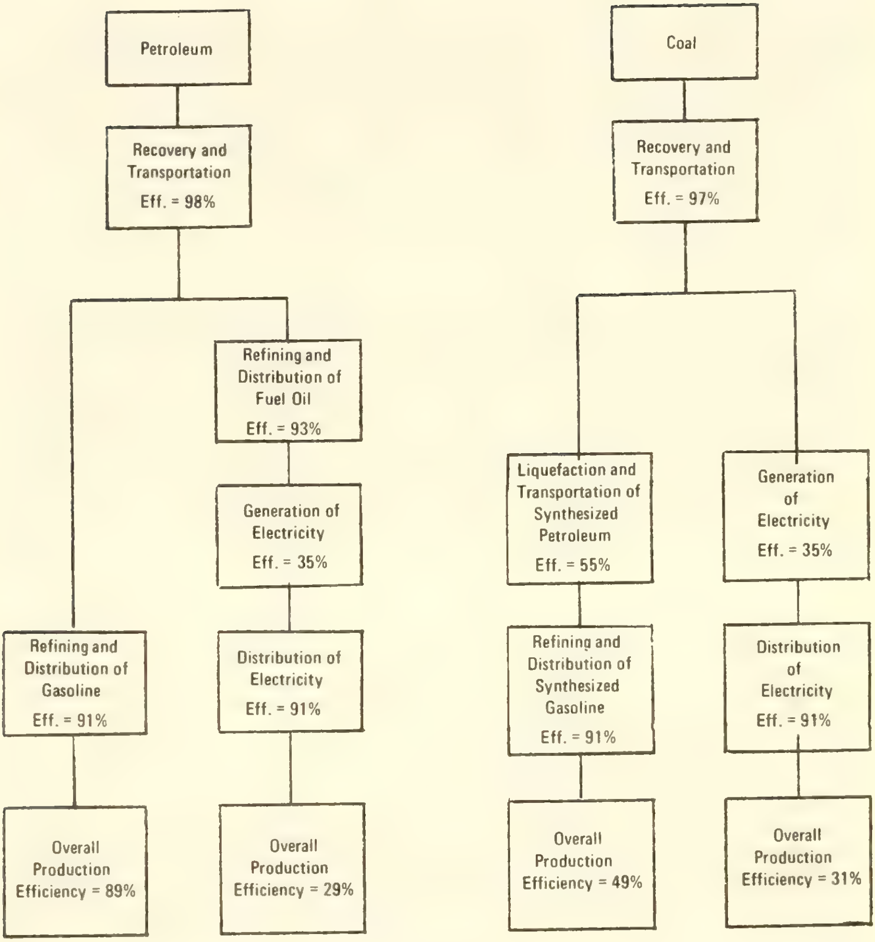

Petroleum
Recovery and Transportation Eff. = 98%
Refining and Distribution of Fuel Oil Eff. = 93%
Generation of Electricity Eff. = 35%
Refining and Distribution of Gasoline Eff. = 91%
Distribution of Electricity Eff. = 91%
Overall Production Efficiency = 89%
Overall Production Efficiency = 29%
Coal
Recovery and Transportation Eff. = 97%
Liquefaction and Transportation of Synthesized Petroleum Eff. = 55%
Generation of Electricity Eff. = 35%
Refining and Distribution of Synthesized Gasoline Eff. = 91%
Distribution of Electricity Eff. = 91%
Overall Production Efficiency = 49%
Overall Production Efficiency = 31%

Figure 1.

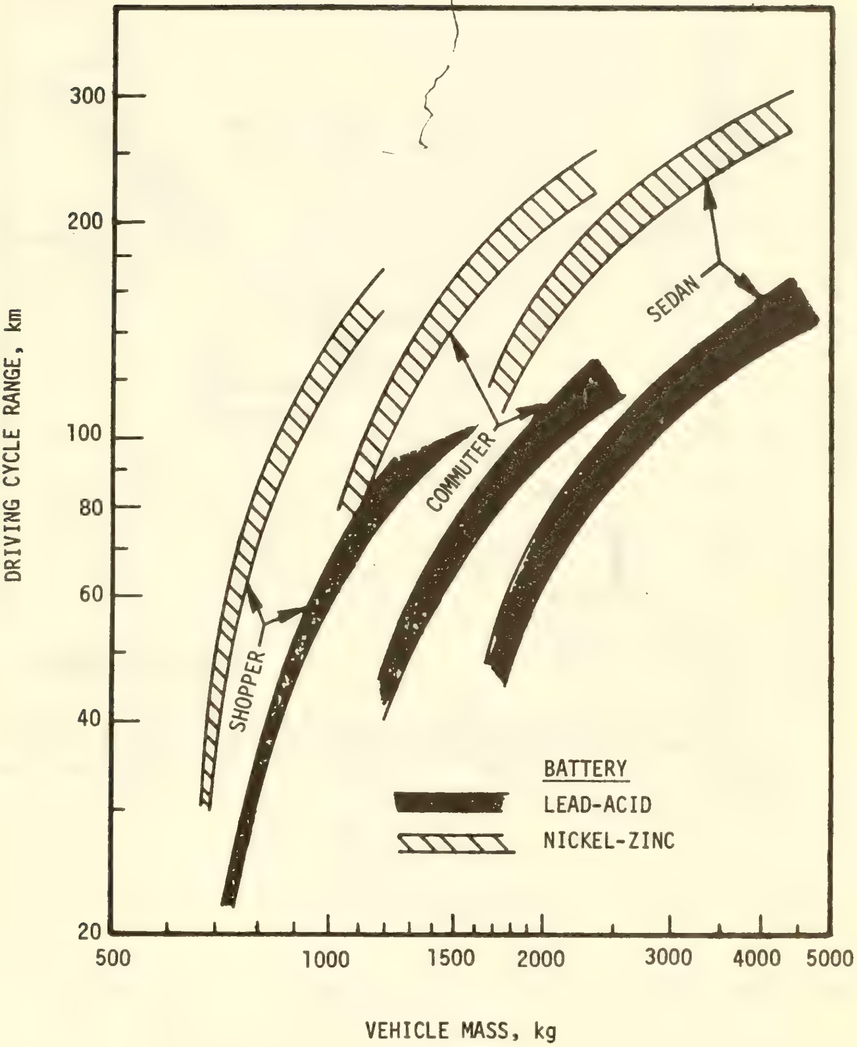

DRIVING CYCLE RANGE, km
300
200
100
80
60
40
20
500
1000
1500
2000
3000
4000
5000
VEHICLE MASS, kg
SHOPPER
COMMUTER
SEDAN
BATTERY
LEAD-ACID
NICKEL-ZINC

FIGURE 2

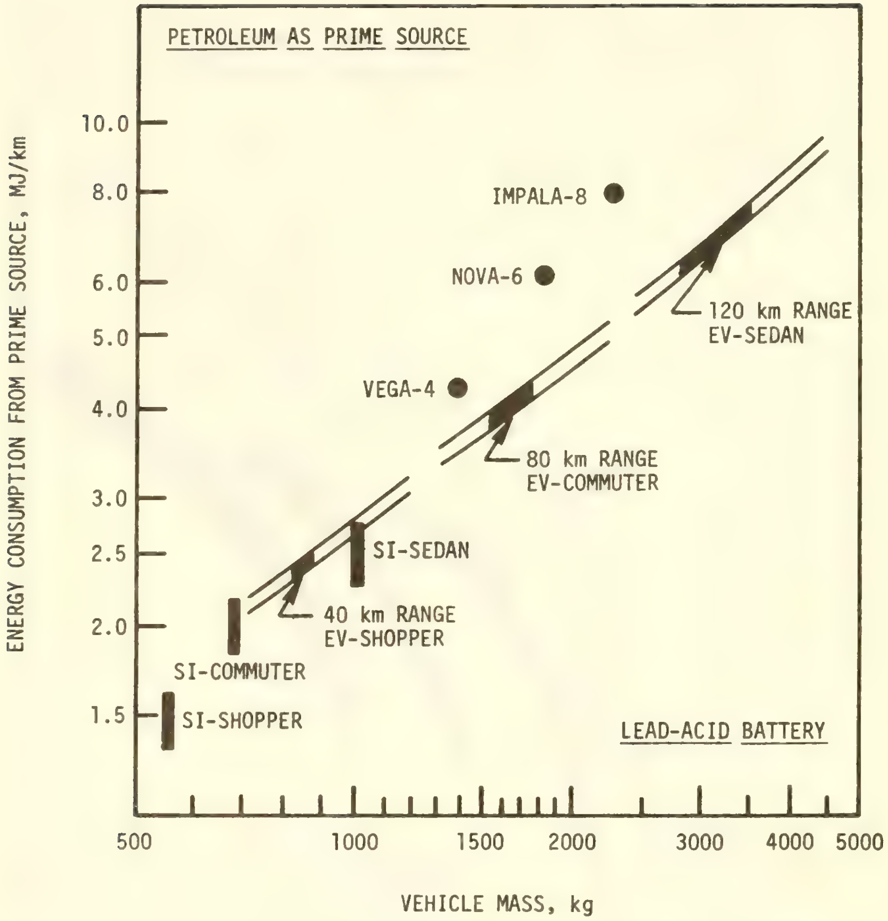

PETROLEUM AS PRIME SOURCE
ENERGY CONSUMPTION FROM PRIME SOURCE, MJ/km
10.0
8.0
6.0
5.0
4.0
3.0
2.5
2.0
1.5
IMPALA-8
NOVA-6
VEGA-4
120 km RANGE
EV-SEDAN
80 km RANGE
EV-COMMUTER
SI-SEDAN
40 km RANGE
EV-SHOPPER
SI-COMMUTER
SI-SHOPPER
LEAD-ACID BATTERY
500
1000
1500
2000
3000
4000
5000
VEHICLE MASS, kg

FIGURE 3

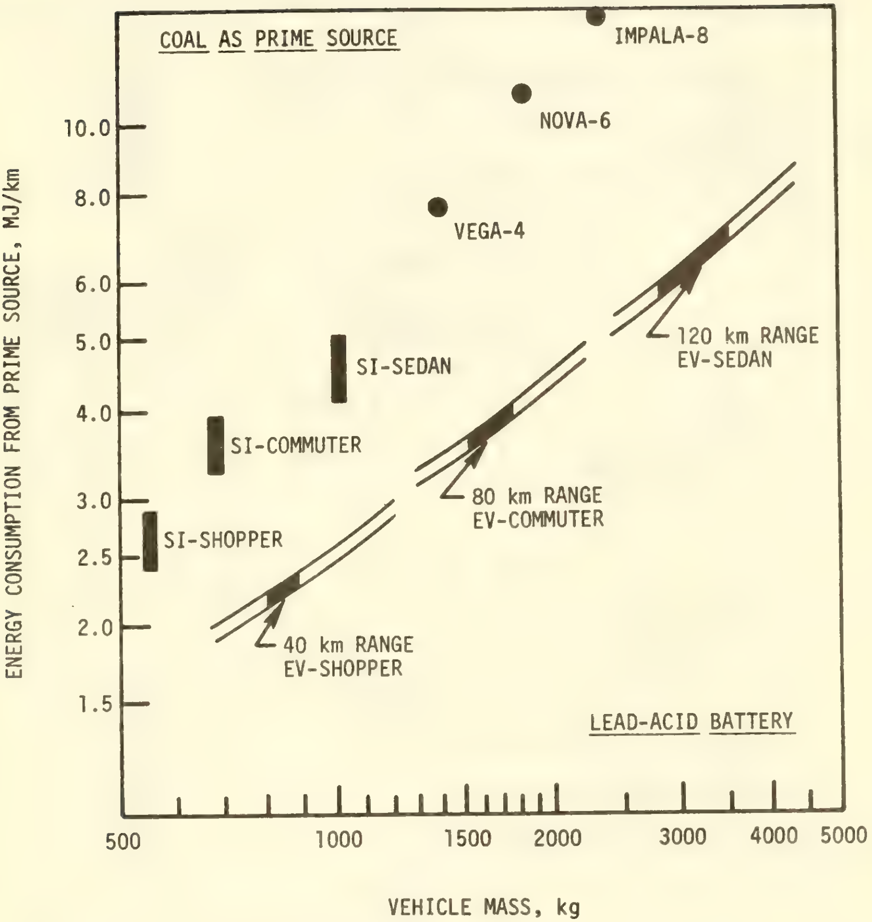
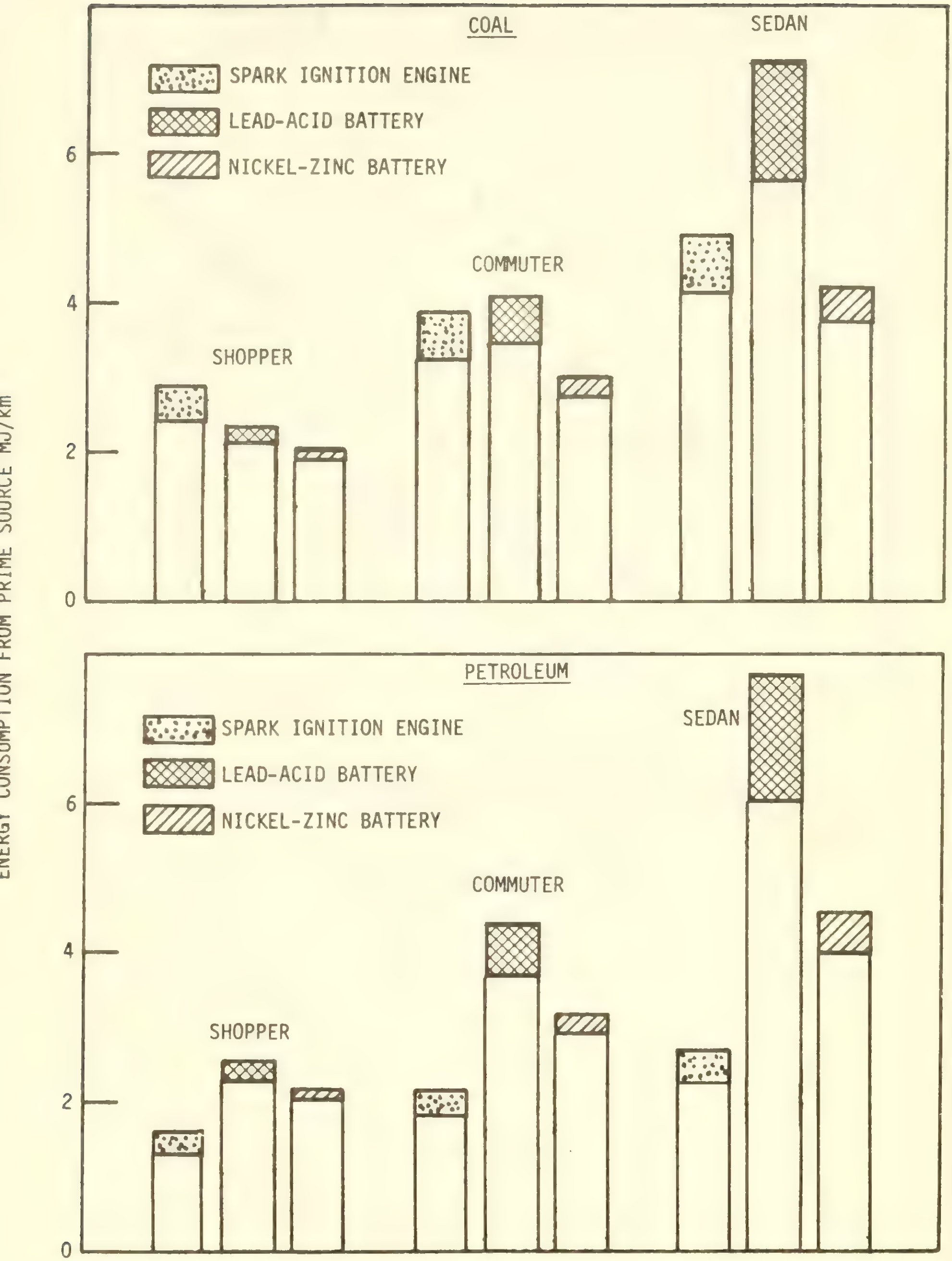

COAL AS PRIME SOURCE
IMPALA-8
NOVA-6
VEGA-4
SI-SEDAN
SI-COMMUTER
SI-SHOPPER
120 km RANGE EV-SEDAN
80 km RANGE EV-COMMUTER
40 km RANGE EV-SHOPPER
LEAD-ACID BATTERY
ENERGY CONSUMPTION FROM PRIME SOURCE, MJ/km
10.0
8.0
6.0
5.0
4.0
3.0
2.5
2.0
1.5
500
1000
1500
2000
3000
4000
5000
VEHICLE MASS, kg

FIGURE 4



PRIME SOURCE ENERGY UTILIZATION
COMPARISON OF GASOLINE AND BATTERY-
ELECTRIC POWERED URBAN VEHICLES

FIGURE 5

Attachment E

POLLUTANT EMISSIONS IN GRAMS PER MILE OF TRAVEL IN LATE 1970'S

	I.C. Engine Automobile (EPA Standards)		Electric Car (EPA Standards For New Power Plants) Coal Fired
	1976	1978	
Unburnt hydrocarbons	1.5	0.41	
Carbon monoxide	15	3.4	
Oxides of Nitrogen	3.1	0.4	2.53
Sulfur Dioxide	0.11*	0.11*	4.35
Particulates	0.1*	0.1*	0.36
Total mass	19.81	4.42	7.24
Health weighted equivalent based on Primary National Air Quality Standards	2.84	0.56	6.53

Since the relative effect of the above pollutants on air quality differs widely, it is more meaningful to compare them on a health weighted equivalent basis using Primary Ambient Air Quality Standards established by EPA. The above data show that replacing an I.C. engine car by an electric car to transfer primary energy source from petroleum to coal would increase air pollution by a factor of 2.3 in 1976 and almost twelve times in 1978.

The electric car for which the above emissions were calculated matches the performance of a present-day compact automobile, including air conditioning, and assumed that high energy density batteries 100 watt-hours per pound would be available.

The emissions standard for coal fired plants would necessitate coal with 0.8% sulfur. Since the bulk of U.S. coal has over 2% sulfur, scrubbers which may add 20-30% to the cost of an electric power plant would be required.

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*There are no standards presently proposed for SO_2 and particulate emissions. The SO_2 value is based on 0.03% sulfur content in gasoline, which is considered average. Particulate value is in agreement with a preliminary Federal proposal, and the 1976-78 emission control systems should meet this level with unleaded fuel.

Attachment F

impacts of electric car use in st. louis, philadelphia, and los angeles

william hamilton

FOR PRESENTATION AT

CONTRACTOR'S COORDINATION MEETING
ADVANCED AUTOMOTIVE POWER SYSTEMS DIVISION
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

8 MAY 1975
ANN ARBOR, MICHIGAN

GENERAL RESEARCH CORPORATION
P.O. BOX 3587, SANTA BARBARA, CALIFORNIA 93105

In June of 1973, under contract to EPA, General Research Corporation undertook an eighteen-month study of energy, environmental, and socio-economic impacts of electric car use in the Los Angeles region. A second study, to be concluded in August, 1975, was begun a year later to analyze impacts in the St. Louis and Philadelphia regions. This discussion draws on both studies.

Key characteristics of the three regions under study are shown in Chart 1. They differ markedly not only in size, as the chart shows, but also in their relative dependence on coal, petroleum, and nuclear power, on their meteorological conditions, and on their historical dependence on the automobile. For the future, however, baseline projections made in the electric car sutides show increasing similarity, especially in patterns of automobile use and growing dependence on nuclear electric power. Projected population growth rates for the three regions are roughly equal and are all under one percent per year.

CHART 1

STUDY REGIONS

	AREA (SQ MI)	1970 POPULATION (MILLIONS)	1970 AUTOS (MILLIONS)
ST LOUIS	4100	2.4	0.9
PHILADELPHIA	3800	5.1	1.8
LOS ANGELES	8700	9.7	5.1

Electric cars characterized originally in the Los Angeles study were used as a basis for the St. Louis and Philadelphia impact analyses. They utilized four representative battery technologies: high-performance lead-acid electric vehicle batteries, nickel-zinc alkaline batteries, zinc-chlorine batteries, and high-temperature molten salt batteries. A computer program was developed to model battery discharge while meeting power requirements of electric cars for urban driving. The SAE Metropolitan Area Driving Cycle for electric cars was used in this program; it calls for a stop each mile, an average speed of 24 mph, and an energy requirement per mile very near that of the Federal Driving Cycle.

After a parametric analysis, the specific car ranges of Chart 2 were selected for the impact analysis. The electric cars were efficient four-passenger subcompacts with performance slightly below that of current low-performance conventional subcompacts; they were capable of accelerating from 0 to 40 mph in 10 seconds, and of cruising on a freeway at 60 mph. At a constant 30 mph on a level road, car ranges would be

CHART 2

ELECTRIC CAR CHARACTERISTICS

BATTERY TYPE	LEAD-ACID	NICKEL-ZINC	ZINC-CHLORIDE	LITHIUM-SULFUR
CAR WEIGHT, LBS	3975	3530	2950	2575
URBAN RANGE, MI	54	144	145	138
BATTERY WEIGHT, LBS	1500	1090	570	300
ENERGY CONSUMPTION, KWH/MI	0.79	0.51	0.41	0.45

over twice those shown for urban driving; in hilly terrain or near the end of battery life, however, they could be significantly less.

Characteristics of batteries used in the electric cars are shown in Chart 3. The lifetimes shown assume urban driving of about 30 mi/day. For the lead-acid battery, the projected range of lifetimes is based on current experience; the longer life projection is optimistic. For the nickel-zinc and zinc-chlorine batteries, the indicated lifetimes assume that developers' goals for lifetimes of 400 and 500 deep discharges, respectively, will be achieved, and that life with partial discharges will be increased in inverse proportion to discharge depth. For the lithium-sulfur battery, which must be maintained at a very high temperature, the indicated lifetime range is assumed to be independent of use. Cost and life characteristics for the zinc-chlorine and lithium-sulfur batteries are relatively uncertain, and the figures in Chart 3 are quite optimistic.

CHART 3

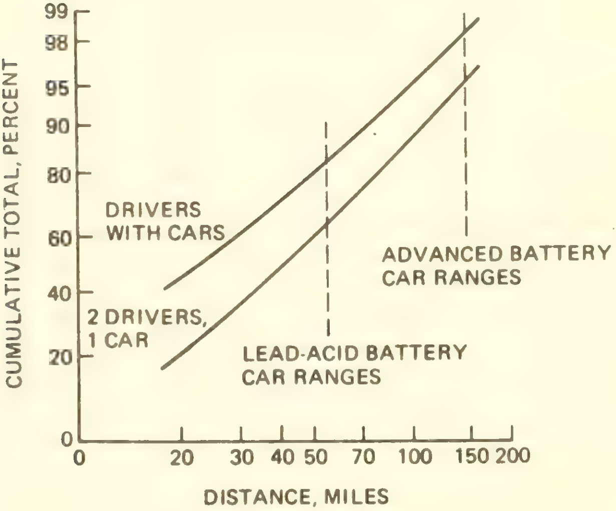
CAR BATTERY CHARACTERISTICS

TYPE	LEAD-ACID	NICKEL-ZINC	ZINC-CHLORIDE	LITHIUM-SULFUR
WEIGHT, LBS	1500	1090	570	300
AVAILABLE ENERGY, KWH/LB	13	44	70	140
ENERGY EFFICIENCY, PERCENT	46	66	70	62
LIFE, YEARS	1.3-3.4	5.8	7.3	3-5
COST, 1973 DOLLARS	1200	4380	600	600

The electric car ranges of Chart 2 were selected after a new analysis of Los Angeles travel data which had been collected in an extensive 1967 survey. Chart 4 shows the resultant distribution of driving distances on the survey day for drivers with cars exclusively available to them, and for drivers sharing a single car. In all three regions, high auto ownership rates are projected so most drivers will have cars exclusively available. Furthermore, daily annual auto usages in the three regions are approximately equal, and are increasing rather slowly. Chart 4 reveals that the cars of Chart 2 with 145-mile range would be inadequate on only 2% of urban driving days. The car with 54-mile range, however, would be inadequate on about 1 driving day out of 6, a frequency considered unacceptable. As a secondary car in a two-car household, however, where longer trips were accomplished by the primary car, 54-mile range could be adequate on over 97% of driving days. Roughly one out of six cars will be in this category by 1980.

CHART 4

DISTRIBUTION OF SURVEY DRIVER TRAVEL



The energy use of electric and conventional cars is projected and compared in Chart 5. Here the electric cars are those described in Chart 2. Their energy use per mile is expressed in terms of heat energy required to operate the electric power station providing recharge power. Average generation efficiency of 36% and distribution efficiency of 92% are assumed.

The energy use of the average ICE car in Chart 5 improves substantially in the future, partly because of a projected continuing shift to smaller cars, partly because of a projected improvement in efficiency of energy use for each size class of car. These projections are, in the longer term, compatible with Federal legislation under development in 1973-74 and with the DOT-EPA report to Congress on automotive energy consumption.

Despite the major improvement in Chart 5 projected for the average ICE car, the electric cars would require less energy per mile. This

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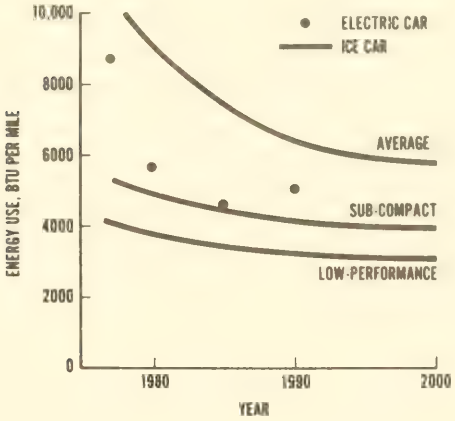
CHART 5

COMPARATIVE ENERGY USE



comparison, however, is not entirely fair, because the average ICE car is both larger and more powerful than the electric subcompact of Chart 1. Accordingly, Chart 5 also shows projected energy use for ICE subcompacts comparable in size to the electric cars, both with performance typical of current US subcompacts and with low performance like that of the electric cars. In comparison with these subcompacts, the electric cars use considerably more energy. This is largely attributable to their much greater weight. The lead-acid battery car, for example, weighs over 60% more than the typical subcompact, and requires additional energy per mile in almost the same proportion.

In Los Angeles, where a very mild climate prevails, waste heat from the electric motor and controller is sufficient for winter temperature control and air conditioning is not essential in the summertime. In St. Louis and Philadelphia, however, which are both colder in winter and hotter in summer than Los Angeles, both supplementary winter heating and summer air conditioning are necessary. Additional energy requirements estimated for this purpose are shown in Chart 6 as a percentage of the recharge energy required for average daily driving of thirty miles. Supplemental heating in the peak month, January, increases energy use over that for propulsion alone by ten to thirteen percent, depending on battery type in the electric car. Over the full year, average extra energy use for heating would be much less, of course. To minimize withdrawal of energy from the propulsion battery, pre-heating of the electric car directly from the power line before its daily usage begins is desirable. Estimated pre-heat requirements are accordingly included in Chart 6.

Air conditioning requirements estimated in Chart 6 assume a 2.3 kW cooling capacity, adequate for maintaining interior comfort in ambient temperatures over 100° F. Peak-month utilization would be higher in St. Louis than Philadelphia owing to substantially higher average daily maximum temperatures. Over the full year, average cooling energy requirements are estimated to be on the order of those for supplemental heating and pre-heating.

CHART 6

ADDITIONAL ENERGY FOR TEMPERATURE CONTROL

(PERCENT OF BASIC RECHARGE ENERGY)

	ST LOUIS	PHILADELPHIA
SUPPLEMENTAL HEAT		
JANUARY	10 - 13	10 - 13
FULL YEAR	2.4 - 3.1	2.6 - 3.4
PRE-HEAT		
JANUARY	9 - 18	9 - 18
FULL YEAR	3.8 - 6.8	3.8 - 6.8
COOLING		
AUGUST	15 - 20	11 - 14
FULL YEAR	3.4 - 4.4	2.4 - 3.1

After allowance for the minority of electric cars which would probably not be equipped with air conditioners, plus a reduction in preheating requirements for electric cars parked overnight in garages rather than outdoors, average overall energy requirements for temperature control are estimated at six to ten percent of recharge energy for propulsion alone.

Under maximum heating or maximum cooling requirements, electric car range would be reduced by about sixteen percent for all battery types. Since maximum ranges are much greater than driving requirements for most days, as shown in Chart 4, the overall result would be that drivers would have to choose between comfort and driving range on only a few percent of driving days.

Growth in per capita electric power demand was projected at 4 1/2% per year for all three regions, a conservative rate relative to past experience. Hourly demand profiles were individually forecast for the regions for representative days during the full year, and then matched with forecasts of projected supply by energy sources. A typical result is shown in Chart 7.

Chart 7 shows the level of load, as a percent of the annual peak, which is exceeded during different fractions of the year. The lower curve on the chart is the baseline forecast for the case of zero electric car use. Also shown are the effects of recharging electric cars when they are used to replace 20% and 80% of conventional cars in the region. As Chart 7 shows, nuclear power stations are planned to meet the base load in St. Louis in 1990. They would operate whether or not electric cars were being recharged. The next cheapest source, coal, would be used to meet most of the variations in demand level, and consequently would supply most of the recharge power for electric cars. A relatively small portion of annual electric energy supply, required only during peak periods, would be met from a number of other sources, including hydro-

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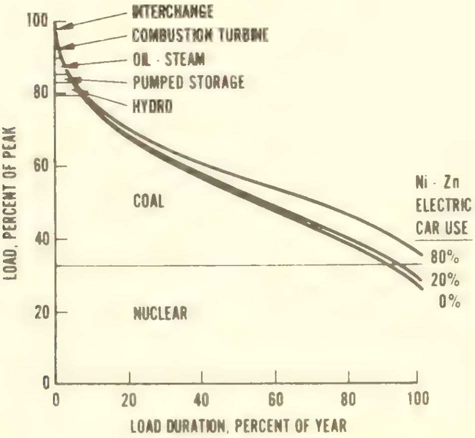
CHART 7

ELECTRIC UTILITY LOAD-DURATION PROFILE

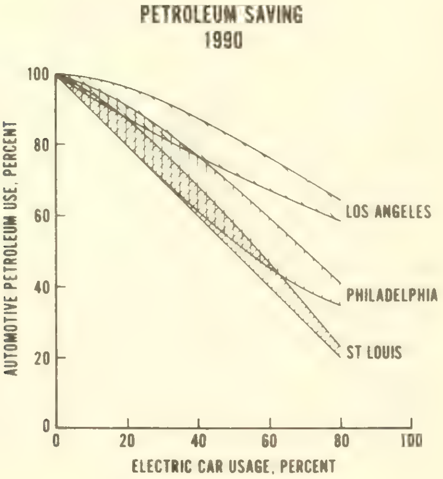
ST LOUIS, ~~1970~~ 1990



electric plants, pumped storage, oil-fired steam plants, combustion turbines, and purchases from other regions. Only the last three of these power sources involve petroleum fuels. As the chart shows, even at 80% electric car use almost no recharge energy would be required from these sources. Similar charts for Philadelphia and Los Angeles would show increasing reliance in both regions on petroleum, with the result that electric car use would be much more dependent on petroleum fuel.

Chart 8 shows estimated 1990 petroleum use in the three regions as a function of electric car usage. Evidently potential petroleum savings with electric car use are greatest in St. Louis and least in Los Angeles. For each region, a band of possibilities is shown corresponding to the type of cars assumed to be replaced by electric cars. The lower boundary, corresponding to minimum petroleum saving, would result if electric cars replaced subcompacts first, then larger cars in order of

CHART 8



size. At 100% electric car usage, only average cars can be replaced, of course; but in 1990, sufficient recharge power will not be available for 100% electric car use on peak-demand days.

Chart 9 shows projected regional emissions of air pollutants in 1990 as a percentage of annual emissions in the early 70's. In these reference years, all three study regions exceeded air quality standards for oxidant concentrations, largely as a consequence of high hydrocarbon (HC) emissions, and also exceeded carbon monoxide standards. Automotive emissions were major factors in both these pollution problems. SO_X levels also exceeded air quality standards; here electric power plant emissions were the major factor, with autos contributing very little. In the projections of Chart 9, future emissions from stationary sources were assumed to comply with local regulations, which in turn generally follow Federal regulations. For vehicular sources, emissions in St. Louis and Philadelphia were assumed to comply with the delayed schedule

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CHART 9

AIR POLLUTANT EMISSIONS
(PERCENT OF 1970 - 1972 AVERAGE)

		1990 - BASELINE	1990 - 80% ELECTRIC CARS
HC	ST LOUIS	44	37
	PHILADELPHIA	62	55
	LOS ANGELES	19	16
CO	ST LOUIS	27	17
	PHILADELPHIA	28	18
	LOS ANGELES	11	8
SO_X	ST LOUIS	72	85
	PHILADELPHIA	68	80
	LOS ANGELES	158	180

of emissions standards under the Clean Air Act of 1970 recently proposed to the Congress by EPA. These changes would delay imposition of the most stringent emissions levels from 1977 to 1982. In the Los Angeles projections, however, this delay was not assumed. It appears likely that nationally the delay will be adopted, but California has already requested a waiver of the delayed schedule in favor of that now in effect.

In the 1990 baseline projection of Chart 9, there are substantial reductions in air pollutant emissions even in the absence of electric cars. For Los Angeles, where no delay in stringent vehicular emissions control is assumed, the baseline changes in HC and CO are particularly dramatic. Additional projected reductions in Chart 9 due to very high usage of electric cars appear relatively modest in comparison. Because of the recharge power generation, SO_X emissions will be increased over the baseline by electric car use in all three regions. Use of stack gas scrubbers, which are not now implicit in the baseline projection, may make possible a major reduction in the level of SO_X emissions, both with and without electric cars.

For Los Angeles, the emissions reductions in the baseline projection of Chart 9 will dramatically improve air quality, but not quite to the stringent Federal standards. The additional modest changes due to electric car use will not make the difference between compliance and non-compliance. Air quality projections based on the emissions projections of Chart 9 have not yet been completed for St. Louis and Philadelphia.

Comparative costs for conventional and electric cars are shown in Chart 10. Overall, as the bottom line shows, the nearer-term electric cars are expected to be much more expensive than their conventional counterparts, primarily because of battery depreciation. The range shown for the lead-acid electric car results from the range of possible battery lifetimes in Chart 2. Vehicle life is assumed to be 100,000 miles for the conventional subcompact and 120,000 miles for the electric

CHART 10

1990 LIFE-CYCLE COSTS
(1974 CENTS PER MILE)

	ICE SUB-COMPACT	ELECTRIC CARS			
		LEAD ACID	NICKEL-ZINC	ZINC-CHLORINE	LITHIUM-SULFUR
DEPRECIATION					
VEHICLE	2.4	2.7	2.7	2.7	2.6
BATTERY	0	4.0 - 10.3	5.6	0.9	1.3 - 2.2
UPKEEP	2.5	1.5	1.2	1.2	1.2
FUEL	1.2	2.8	1.8	1.5	1.6
POLLUTION CONTROL	0.9	0	0	0	0
FINANCING	1.6	2.9	4.1	2.4	2.4
TAXES, ETC.	4.3	4.5	4.5	4.5	4.5
TOTAL	13	18 - 25	20	13	14 - 15

cars. Fuel costs are forty cents per gallon for gasoline (not including tax) and 3.6 cents per kW hour for electricity. Costs in Chart 10 are averages for the three regions; the variation from region to region in total cost is less than a cent per mile. Costs of temperature control are not included; they range from .5 to 1.0 cents per mile for the electric cars. Despite the advantages of electric cars in reduced maintenance and pollution control, they are unlikely to approach the conventional subcompact in overall economy until battery development drastically reduces battery depreciation costs.

Impacts on employment of 100% usage of electric cars are shown in Chart 11. Depending on the type of electric car in use, they range from 0 to a little over 1%. Since these impacts would appear gradually over the considerable period of years required to build up substantial electric car usage, and in any case are much less than the average regional levels of unemployment, they must be considered small. Impacts in Philadelphia

CHART 11

EMPLOYMENT IMPACTS

100% ELECTRIC CAR USE
1990

	PERCENT CHANGE IN EMPLOYMENT	
REGION	**MINIMUM**	**MAXIMUM**
ST LOUIS	–0.2	–1.1
PHILADELPHIA	0	–0.9
LOS ANGELES	–0.2	–1.2

are generally less than in St. Louis and Los Angeles because most eliminated jobs are in gasoline filling stations, and Philadelphia has historically had fewer employees per automobile in these stations.

In summary, it may be concluded that the applicability of electric cars to urban driving is surprisingly high, even with lead-acid batteries. Potential energy savings due to electric car use are not large, but petroleum savings in 1990 and 2000 can be important where coal-fired and nuclear power plants provide recharge power. Air quality improvements due to electric car use are likely to be relatively modest owing to the major improvements in progress for conventional automobiles. Until battery depreciation costs are substantially reduced by advancing technology, electric cars will be at a substantial cost disadvantage relative to conventional subcompacts. Effects of electric car use on regional employment will be minor.

Mr. HOLZWARTH. Mr. Chairman and members of the House Subcommittee on Energy Research, Development, and Demonstration.

As Mr. Blanchard mentioned, I am James C. Holzwarth, and with me is Dr. Paul D. Agarwal, who is head of our electrical engineering department at the research laboratories of GM, and we do appreciate the opportunity to comment on H.R. 5470.

As we move toward energy self-sufficiency, when presumably nearly all of our electric power will be derived from coal and/or nuclear sources, a large-scale use of petroleum and natural gas by public utilities will no longer be needed, then the electric car may be an important contender in fulfilling our long-range transportation needs.

We believe that governmental backing could foreshorten the time required for developing electric propulsion technology to the stage of commerical feasibility. Furthermore, the Government needs to pave the way for electric vehicles through enabling legislation, as well as administrative action, if electrics are to be permitted to enter into an existing vehicles population.

For many years, General Motors has committed substantial resources to developing alternatives to the current automobile engine. We are committing substantial effort and resources to alternate fuel engines, small diesels, gas turbines, stratified charge engines, and others. These are referenced in our statement. Our total alternative power source research and engineering expenditures for the year 1975 are expected to be about $50 million. These expenditures since 1967 are detailed in attachment A.

Our efforts also include a great deal of work on propulsion systems with potential for the longer-term future. Electric vehicles, of course, are in that category. At our research laboratories alone, about 30 people are working intensively on advanced propulsion batteries and fuel cells. We are carrying on basic research on electrode mechanisms and the electrode processes that lead to deterioration upon cycling. We are also carrying out research on materials for electrodes, separators, and electrolytes, to minimize battery weight while achieving adequate life. Others in our electrical engineering department, represented by Dr. Agarwal, at the General Motors Research Laboratories, are looking at optimized electric drive systems, including traction motors, controls, and electronics needed with these advanced batteries.

General Motors is also concerning itself with advanced battery design and manufacturing technology and with the projected costs for making these advanced battery systems. Engineers at our engineering staff and, again, at our research laboratories, are carrying out analytical studies to determine the levels of battery technology required before vehicles of various sizes weights, ranges and performance capabilities can be considered. We feel that we will be prepared on the engineering and manufacturing details when advanced energy storage devices become feasible for production vehicles.

Over the past decade, we have built and tested a series of electric and hybrid vehicles using the most advanced state-of-the-art components, to develop and optimize motor and control systems, and to gain actual operating experience. Characteristics of these cars are documented in attachment B.

We have also purchased or test-driven electric vehicles manufactured by other companies. Even though we had high expectations with respect to these vehicles, the results were frustratingly disappointing.

One simple and inexorable fact kept bringing us back to reality with every fresh look. Existing batteries, including the most energetic batteries commercially available, couldn't begin to do an effective job of moving people in comparison with gasoline.

To place this in proper perspective, for the same work done at the wheels as by 20 gallons of gasoline, or 58 kilograms of gasoline, in an internal combustion engine vehicle, one would require about 5,000 kilograms of lead-acid batteries or 600 to 700 kilograms of the best projected batteries. It becomes obvious why electric cars will continue to be much heavier than their internal combusion engine counterparts designed for the same mission.

Because of this battery limitation, electric vehicles are unable to match the performance and range of gasoline-powered vehicles. They suffer from greater weight, both the battery weight and the necessary added vehicle structure, and this weight penalty demands more propulsion energy. In addition, the original cost is high and, when amortization is considered, the operating cost also is high.

In designing batteries for electric vehicles, there are tradeoffs among specific power, which determine vehicle performance, specific energy, which affects vehicle range, and battery life, which influences vehicle operating cost. The Electrovair II, shown on page 1 of attachment B, was built using silver-zinc batteries as a power source. It had good performance, and it nearly matched the gasoline engine Corvair performance, and this made it effective in mixing with regular traffic. But this performance was attained at serious sacrifice of battery life and range capability.

Silver-zinc batteries would be impractical for wide transportation use because of high initial cost. The batteries in Electrovair II contained about $10,000 worth of silver at today's market prices. But they were chosen for the experiment because the technology for building them was available. In addition, they matched the performance capabilities expected from some of the advanced batteries now being developed for use beyond the next decade.

Our 512 electric vehicle, the one that Mr. Blanchard mentioned was downstairs, and the one shown in attachment B, used commercially available batteries, had a top-speed capability of only 30 to 45 miles per hour and cannot safely mix with existing traffic.

Incidentally neither of the two cars that I've mentioned would come close to meeting current Federal motor vehicle safety standards. If they were redesigned to conform to these standards, the added weight would further degrade their performance, range, and operating economy. When vehicle weight is added to meet safety and/or performance requirements, additional weight must be added to the chassis, drivetrain, suspension, and other components to maintain vehicle performance and structural integrity.

Have we given up on electric propulsion? No; indeed we have not But for the present we feel that building more electric vehicles is a waste of resources. The real problem—and really the only technological roadblock to electric personal transportation—is the battery system itself. No technological breakthroughs are required for devising electric drive systems, motors, controls, choppers, inverters, or other circuitry, although substantial engineering effort would still be required to tailor these electrical components to individual vehicles. There are many ways available to design and build adequate hardware to fit specific vehicle needs.

We are now concentrating our efforts on basic electrochemical research and on engineering development of advanced batteries. Zinc-nickel oxide, sodium-sulfur and lithium-sulfur currently offer at least some promise of providing a reasonable combination of specific power, specific energy, durability, and cost for future electric vehicles. We have looked at other systems as well: lithium-chlorine, zinc-air, and zinc-chlorine, for example, and have considered these too costly or too impractical.

Mr. Chairman, Section 2 of H.R. 5470, the "findings" which presumably form the basis for this proposed legislation, contains a number of statements which are incomplete or inaccurate. Thus, they could provide erroneous conclusions about prevailing conditions and faulty assumptions on which to base legislative action.

In the interest of conserving time here this morning, I will not read the section of my prepared statement which discusses these findings. However, it will be appreciated if the full statement may appear in the record.

If any of you are following the text, I am jumping now to the bottom of page 15.

Mr. BROWN. As I indicated at the beginning, the full text will be placed in the record, so you may go ahead.

Mr. HOLZWARTH. Thank you.

General Motors does not believe that much can be gained at this time by subsidizing the sale of electric vehicles. The capability of electric vehicles with state-of-the-art battery technology is well-known. Until better batteries are developed, those capabilities are not likely to be improved drastically.

We believe the production, at this time, of a significant number of electric vehicles would: Be costly and without real benefit; be uninformative regarding the real problem, the batteries; mix a low performance vehicle population with the current automotive population; and not move us close to energy self-sufficiency in a reasonable time, since some petroleum conserved in the refining of less gasoline probably would merely be consumed in extra powerplant generation, especially for peaking power.

The 352 electric vehicles currently being readied for the Postal Service should comprise an adequate sample to demonstrate capability and determine performance. Presumably these new vehicles employ the latest in commercial battery technology and will provide a test in service best suited to this type of vehicle.

We question the need for the Government to subsidize products for sale in a competitive market. Private industry is better equipped and sufficiently motivated to respond to that phase of the problem. There is a role for Governemnt to play in supporting research and development on advanced battery and fuel cell technology where the real bottlenecks to commercial feasibility exist.

Electrode processes, electrode catalysis, development of better battery materials and improved cell durability are areas which now represent critical bottlenecks in the industry's efforts on battery-powered cars. Government support of research in these areas would supplement rather than duplicate the efforts of industry and thus make real contributions to progress.

The second area for useful Government effort concerning the electric car is directed toward energy and traffic management considerations in which the Government should and must carry the major responsibilities. Some of these issues and value judgments are beyond the appropriate role of business.

It is important to understand the social, economic and environmental impact of electric vehicles on a nation where a shortage of electric power capacity is threatened. Studies of urban traffic problems and the effects of added congestion resulting from slower electric vehicles mixing with other vehicles are both necessary and desirable.

It would be advisable for the Congress to have available a better understanding of a feasible and appropriate role for electric cars in the Nation's energy policy before committing large amounts of public funds to promote widespread use of electric vehicles. When nuclear power and coal assume the dominant role in generating electrical power, then the electric car would begin to assume a more effective role in our Nation's energy and transportation systems.

As higher performance batteries with greater durability, power and energy storage capability at reasonable cost are developed, combined with increased electric power generation capacity based on nuclear power, battery-powered electric cars should become more competitive with alternates. When the economics of electric cars become more favorable, there will be no need for the expenditure of public funds to promote them. Our competitive system will insure that the products are provided as the commercial opportunity develops.

Thank you.

Mr. Brown. Thank you very much, Mr. Holzwarth. Your testimony and the references in the attachment are a very valuable contribution to the committee's consideration, and we appreciate the work that you've put into assembling this material.

Mr. Blanchard, would you like to propound some friendly questions to your constituents?

Mr. Blanchard. Only one, Mr. Chairman.

I take it from what you're saying, Mr. Holzwarth, that you don't support this bill. Or do you?

Mr. Holzwarth. Our answer to that is that we support portions of the bill.

The part that we think is clearly premature is the portion covering the building of large numbers of electric vehicles at this state of the development of the battery technology. That part of the bill we think is just premature.

Mr. Blanchard. So then, consistent with the recommendations you have outlined in your statement, which you didn't read and which we all have, you would support the bill?

Mr. Holzwarth. The portions on R. & D. financing and on studies aimed at determining what the impact of electric vehicles will be on the environment and on the traffic problem and on the utilization of energy, we feel, are very important and certainly an effective thing to be done by the Government.

Mr. Blanchard. Inasmuch as a number of the other committee members have been spending more time on this legislation, I would like to yield back to you, Mr. Chairman. Thank you.

Mr. Brown. Feel free to interrupt at any time that you would like, Mr. Blanchard.

Mr. Ottinger, do you have any questions?

Mr. Ottinger. Thank you, Mr. Chairman.

As much as I hate to be cross with one of Mr. Blanchard's constituents——

Mr. Blanchard. Feel free.

Mr. Ottinger. I must say that I find the inertia of the major automobile companies with respect to any kind of innovation to be a matter of terrible concern. We're losing a substantial amount of our American automobile production, and the automobile companies themselves are being hurt by their failure to innovate, to push new technology. The automobile companies insisted that you couldn't build an economical compact car. They continued to insist on that position until a substantial portion of their market was taken away by foreign manufacturers. I think the same thing is going to be the case with the electric car.

You just seem to have such a tremendous investment in the mass production, which has brought the price of the internal combustion engine car down, and for many years below that which any other country could match, that I just find it very disturbing. I would think that you would be the leader in trying to promote this kind of thing, and be on top of it, instead of resisting our effort to push some of these developments, which the automobile companies seem unwilling themselves to push.

With respect to the use of electricity in promoting these cars, it seems quite clear that these cars, for the most part, will not be using peaking power. One of their attractions is that they'll be using off-peak power because they'll be charged at night when the peak is off. So it should permit more efficient power use of our present power generating capacity.

Don't you think that's so? Part of your testimony seems to me to be clearly wrong.

Mr. Holzwarth. May I comment to the first part of your statement there, Mr. Ottinger?

Mr. Ottinger. Yes.

Mr. Holzwarth. We are extremely well aware of the economic situation in the automobile industry and we are doing everything we can within our means, as quickly as we can, to adjust our product lines toward smaller vehicles, lighter weight vehicles. We're spending at an unprecedented rate for us to try to do that just as quickly as possible. It's not an easy task, when we have to finance these things. But we are doing it to our complete product line as quickly as we can, and this fall with the 1976 model year we will have available for sale what is probably the smallest production car that's ever been built in this country.

Beyond that, we expect to redo our entire product line of passenger car vehicles.

I don't know whether that directly answers your question, but investment in existing plant is out the window. We have to build whatever tooling we need to do the job.

To the second part of your question about off-peak recharging, I did not read through that part of my testimony which comments on recharging, and I don't know whether we should take the time now to do that. But one of the findings that led to this H.R. 5470 stated that these electric vehicles would be recharged at night on off-peak hours. But we view that finding only as a presumption. We don't really know what people are going to do.

Now, granted that, through structuring of electric power rates, off-peak charging certainly can be encouraged. But it's our feeling that because of the state-of-the-art in batteries, and because of the limited vehicle range, most of these electric vehicles will be used during daylight hours to perform short-range missions, and the natural tendency is going to be to put those vehicles on charge immediately when that mission is completed, so that there's reserve capacity there for the next mission, because they are seriously range limited.

And so we are saying that that finding really, in our opinion, is a presumption that electric cars will be charged at night, and not a fact that has been proven at this point.

Does that answer your question, sir?

Mr. OTTINGER. No.

Would the real motivation behind your resistance to this legislation be that there are a lot of small entrepreneurs out there who are really trying to do things with this technology and you just want to squelch them because one of them might be successful in providing some competition to the giant multinational corporation that you represent?

Mr. BROWN. That would be called a leading question if we heard it in the courtroom. [Laughter.]

You may handle it in whatever way you wish.

Mr. OTTINGER. These people who are doing this have put a tremendous amount of their own money into it, in terms of in relation to what they have, and have come up with some very interesting things, and you say, "Ignore it. Let GM take care of it."

I don't like it much.

Mr. HOLZWARTH. Maybe I can rephrase your question a little bit to bring it along more technical lines.

My background is technical, not in the business part of the world, so to speak.

General Motors has probably spent more money on development of electric cars than any other company. As a matter of fact, I don't have any facts and figures on what others have spent, and I don't really at this moment have facts and figures on what we have spent—but I'm very confident GM's expenditures are in the tens of millions of dollars for development of electric vehicles. And we haven't done that just to be negative.

We feel, like many of the people in this room, that there is a position for electric vehicles, or there will be in the future. When we started out building electric vehicles back in the early sixties, to assess the state of technology, we did it with confidence that there would be a market there. We continue to look at that market, but it's still our feeling at this point that there have not been sufficient breakthroughs in the energy storage capability to warrant any widespread use of low performance vehicles in an existing population.

Mr. OTTINGER. GM is also a constituent of mine, but I think, in the interest of saving the American automobile industry, that GM would be much better advised to push along faster on actually testing and getting on the road these vehicles, and supporting this kind of legislation to let some of those smaller private entrepreneurs get into this act and actually road test some of the vehicles that have been produced.

I do think that GM has put some money into this research. It's unquestioned. But their desire to keep other private entrepreneurs out, that don't have the money to finance this themselves, and their unwillingness, because of their huge investment in their existing technology, to really put their own cars out on the road.

I read through your attachment showing your work on each one of these vehicles, and after each one it says "abandoned," and that isn't going to further the art.

So I would think you ought to be encouraging the small entrepreneurs in this country to go ahead with this technology.

I have no further questions. Thank you, Mr. Chairman.

Mr. BROWN. Thank you, Mr. Ottinger.

Mr. Hechler?

Mr. HECHLER. I was just weighing your submission of testimony here, Mr. Holzwarth. I congratulate you on several plugs that you made for coal, and we appreciate that in West Virginia.

I assume that what you're saying is that you assume your own efforts in the area of research in electric cars are substantial, and yet you say on page 17:

> It would be advisable for Congress to have available a better understanding of a feasible and appropriate role for electric cars in the nation's energy policy before committing large amounts of public funds to promote widespread use or electric vehicles.

It seems to me that what you are saying is you have spent some, but you have not spent enough, but you are afraid to have Congress provide any additional public funds in this area, and I find that somewhat inconsistent.

In general I share Mr. Ottinger's feeling about the negative nature of this testimony. It's extensive, but rather negative. I guess you meant to convey that impression that it should be negative.

But it seems to me that the buggy whip manufacturers might well have said this same thing about the automobile at one time. Isn't that true?

Mr. HOLZWARTH. That's very possible, Mr. Hechler.

I really, and sincerely, feel that we are trying to be helpful, and not trying to just be negative. Certainly there are some negative statements in here aimed, really, at the comment I gave to Mr. Blanchard's question about the timeliness of this demonstration.

There are, we believe, very good and proper things that the Government could and should do to promote the development of viable electric vehicles. We are trying to be helpful by sharing with you our experiences on electric vehicles, which have told us that they are not ready to mix in large numbers with an existing population. But they can have a very restrictive role, even today, in performing some missions.

But what we are saying is: before we build a lot of vehicles and get them out into the hands of the public everywhere we should be sure about these other impacts.

That particular statement of mine on energy policy which you referred to, I think is directed at the various groups in the Congress now that are considering energy, and it perhaps is a caveat about working at cross purposes.

Mr. OTTINGER. Would the gentleman yield for one question?

Mr. HECHLER. Yes, I'll yield.

Mr. OTTINGER. If we pass this legislation would General Motors participate? Would they make an application for funds under this act? Do you know what their attitude at this point would be, or interest in participating?

Mr. HOLZWARTH. I rather think we would. I would like to think about that question a little bit and perhaps supply a written answer. But I think GM would be interested in participating.

Mr. OTTINGER. We would like to have a written answer to that if we could. Thank you.

[The information to be furnished is as follows:]

> If legislation were passed to authorize government purchase of electric vehicles, General Motors would give careful consideration to an opportunity to participate, for, as we said in our statement to the subcommittee, we believe the electric car may be an important contender in fulfilling our long-range transportation needs.
>
> However, we believe it is premature to build a larger number of vehicles until such time as battery technology is further developed. The only technological roadblock to electric personal transportation is the battery system itself. Government funding of research into such areas as electrode processes, electrode catalysis, development of better battery material and improved cell durability would do far more to advance the state of the art of electric propulsion than government support of production of vehicles based on current technology.

Mr. HECHLER. May I repeat your ringing conclusion on page 18, just so it sinks in?

> When the economics of electric cars become more favorable, there will be no need for the expenditure of public funds to promote them. Our competitive system will ensure that the products are provided as the commercial opportunity develops.

I take it that you feel we live under a strictly competitive free enterprise system, and not the necessity for any subsidies or tax writeoffs, or any other of the interferences which do not exist in our modern economy.

Mr. HOLZWARTH. That was a sort of concluding statement, Mr. Hechler.

I had included on page 15 one of the statements I did not read. It is a more explicit statement leading to that conclusion, and if you will permit me, I will go back and read that statement. It's at the middle of page 15:

> One stated purpose of H.R. 5470 is to "demonstrate the commercial feasibility of electric vehicles." Implicit in the term "commercial feasibility" is a demonstra-

tion of the salability of the product. Does the product fulfill people's wants and needs so that they will buy it? Surely, government subsidies for private individuals to encourage use of electric vehicles and government requirements that they be used by the Postal Service and the General Services Administration hardly demonstrate that they are desirable, salable products on their own merits.

That conclusion was really a summary statement, based on the assumption that there was a free market in vehicles.

Mr. HECHLER. Well, I don't know if the airplane would have been developed entirely, or even the railroads themselves entirely, in a free market. It seems to me we gave a few land grants. It seems to me we gave a few subsidies for carrying the mail. It seems to me that the military had a role in the development of aircraft in this Nation, without which we wouldn't have reached the point that we did in air transportation. It seems to me that the CAB gave a few subsidies to airlines, and still does.

So I was just a little bit puzzled about your general conclusion about this pristinely pure, free enterprise competitive system that we're operating under.

Thank you, Mr. Chairman.

That could be classified as a leading conclusion. [Laughter.]

Mr. BROWN. Mr. Thornton, do you have any questions?

Mr. THORNTON. Mr. Chairman, I would like to ask just a couple, if I might.

Mr. BROWN. Can you avoid political argumentation and just ask a question?

Mr. THORNTON. I make no commitment.

Mr. HECHLER. Would the chairman yield?

I believe my argumentation was economic rather than political.

Mr. THORNTON. I do feel it's necessary, as a former representative of the only buggy manufacturer in the United States, to respond to Mr. Hechler's comments about buggy whips.

Mr. HECHLER. Please do.

Mr. THORNTON. I've read your testimony and listened to your response to some of the questions, and there are parts of the testimony which concern me in our effort to move toward more efficient energy uses. There are parts which concern me as reflecting an apparent dilemma in mixing electric vehicles with existing gasoline-powered vehicles.

With regard to the first, I think you accurately state that in existing technology an electric vehicle affords no appreciable increased efficiency in petroleum use, unless the electricity is generated by coal or nuclear energy, and I think it's vital for us to remember that when oil is used for generating the electricity, that converting to electric vehicles does not have the effect of saving this Nation's oil and gas supplies.

I think that is a very useful observation and one that all members of the committee should keep constantly in mind.

With regard to the difficulty of mixing electric vehicle characteristics with those of existing automotive use patterns, the argument is, I think, that electric vehicle technology cannot mix well with traffic, where the automobiles have the capacity of going from zero to illegal in 7 seconds and achieving a top speed of 120 miles per hour.

My question is whether you perceive a need for the automobile manufacturers to work toward automobiles which might take 20 to 30 seconds to reach the maximum legal speed of 55 miles per hour and to have a maximum sustained cruise in the neighborhood of 65 or 70 miles per hour? Do you perceive any need to work toward that kind of an objective?

Mr. HOLZWARTH. Mr. Thornton, I see already that in our efforts to try to achieve maximum fuel economy with our current gasoline-powered vehicles the high performance capability which you're talking about is, I think, the performance of the past and will diminish year by year. Certainly, those top speeds that are illegal, I think, are a thing of the past. They certainly do exist in the existing population, however.

My concern, expressed in this document, over mixing a low performance vehicle population with an existing population is primarily one at the low speeds, such as starting out from a stopped position or trying to cross major thoroughfares with a vehicle that has extremely low performance, has low acceleration characteristics in the zero to 20 miles per hour range, to clear that intersection safely through oncoming traffic. That's my major concern.

Mr. THORNTON. I believe that is a concern, and performance is needed at that level. However, I can't pass this opportunity to express my concern that the automobile manufacturers in this country, while they are making efforts to achieve different types performance characteristics for vehicles, are, it seems to me, in the main saying that what must be traded off for increased gasoline milage is weight and carrying capacity, when there is also the possibility of trading off acceleration and top speed and building a relatively heavy automobile having adequate carrying capacity, which has low performance data, and these other characteristics.

I'm wondering if your company is making any efforts to market, not a light, small, tiny car, but a car having substantial comfort, but lower performance characteristics?

Mr. HOLZWARTH. Those kind of cars I believe that you have reference to are already available in the 1975 model year, at least from General Motors, with reduced engine size, reduced engine weight.

If you will permit me a personal experience, I am driving a car now that is an intermediate size. It has a small six-cylinder engine in it. It's quite low in performance, by comparison with what I had been used to, but it's getting well over 20 miles on a gallon.

Mr. THORNTON. The point is that I think it would be useful for all to know that you can build an automobile today that will get between 20 and 25 and perhaps up to even 30 miles per gallon, having the characteristics which we're talking about.

I'm concerned that over and over again we hear that the tradeoff has to be for decreased vehicle size and weight, when that is not, in fact, correct.

Do you agree?

Mr. HOLZWARTH. I'm still not 100 percent sure I understand your question.

I think a product line to fit the different needs of different people and different families is already available.

Mr. THORNTON. OK.

Mr. Chairman, I really have taken up too much time perhaps, but to wrap it up:

If the automobile manufacturers were to develop an automotive line which had performance characteristics more in keeping with a reflection of our energy problems, and of legal speeds, and the desire to move people safely at those speeds, it would make the problem relatively easier for electric cars to compete, would it not?

Mr. HOLZWARTH. I think you're right, sir, yes.

Mr. THORNTON. Thank you, Mr. Chairman.

Mr. BROWN. Thank you, Mr. Thornton.

Just a question or two, Mr. Holzwarth.

General Motors has made a substantial commitment to small car production, as you indicated. Do you remember when that policy decision was made?

Mr. HOLZWARTH. Sir, I do not.

Mr. BROWN. Do you have a rough idea of the amount of capital that was involved in investment in new plant for the small car production?

Mr. HOLZWARTH. I recall that starting back somewhere 6 months to a year ago General Motors committed itself to major revisions of its product lines—and I'm not certain about these figures. If you would like those, I think it would be better for me to send those to you for the record. It was in the neighborhood of perhaps $1½ billion over a several year period. But I could be wrong about those figures. I'd much rather confirm them and mail you that information, if you would permit me to do that.

Mr. BROWN. Would you do that, please? And I ask because I'm trying to get a measure as to how quickly a corporation like General Motors, which, of course, is the largest manufacturing corporation in the world, can change direction toward a new technology, or a changed technology.

[The material to be provided follows:]

As early as 1967, work was begun on the engine and other components for the subcompact Vega and the first car was produced in June of 1970. This three-year time schedule is fairly representative of automotive lead time requirements. It cannot be compressed a great deal from that schedule because of the time required for designing and building the complex machinery required for mass production.

For example, machinery requiring new engineering design such as transfer lines may require 18–24 months to design and build, providing the suppliers are not overwhelmed with prior orders. More conventional machinery may be more readily available or, if ordered from scratch, may require about a year. Ordinary plant construction can usually be accomplished within the envelope of the lead times required for the machinery and tools.

The finite capacity of the machine tool industry imposes a constraint on large-scale changes. The automobile industry is, in general, following a six-year cycle for major model redesigns, and the capacity of the machine tool industry is consistent with the level of demand created by that cycle. General Motors' requirements for machine tools during the late 1970's will be considerably accelerated by commitments we have made to redesign our products for improved fuel economy. Presumably, other auto companies are also making greater than normal changes in their products. Thus, specific projects could require greater than normal lead time due to the saturation of key component machine tool manufacturers.

GM has embarked on a new car program involving entirely new products—such as the new small car to be introduced in 1976 that is smaller and more fuel efficient than any car now being produced in the United States—as well as modifications of engines, transmissions, drivelines, improvements in aerodynamics and cutting down the power required to operate accessories. At this time, this program is expected to require several billion dollars of new capital investment.

Mr. HOLZWARTH. May I comment on that, sir?

Mr. BROWN. Certainly.

Mr. HOLZWORTH. I do recall that, of course, for the first time in many, many years General Motors went out to the money market to borrow money to finance this tool building program. We watch our budget pretty closely so we don't end up with a lot of deficit spending. But we thought it was so important to do this that we did go out to the money market to borrow substantial sums to finance this returning of our product line toward smaller, lighter weight, more efficient vehicles that get substantially better fuel economy.

Mr. BROWN. My own information, which I don't have at hand, was based upon a recollection of reading a news story a few months back that you had for the first time gone out, and I think it was $600 million, and that it was for the purpose of investing largely in plant for the production of the smaller automobiles.

I just wanted to get the details to that. It would lead me to a question as to how quickly it would be possible to gear up for the production of a major line of electric vehicles, which would pose comparable problems, I would think, assuming that we could agree on a particular type of technology which could be put into production.

Do you wish to offer an estimate as to how long it would take for General Motors to get into the electric vehicle production in a fairly major way assuming, say, we had a battery that was acceptable and agreed upon?

Mr. HOLZWARTH. I hope you'll excuse me if I say that I'm not a manufacturing person; I'm a research and technology engineering person; and I don't really have an answer to that. Once again, I could try to get you one, if you would be satisfied with my mailing you such an answer.

Mr. BROWN. We'd be satisfied with that. We're trying to make the record as complete as possible on it.

[The material to be provided follows:]

It is expected that battery technology will develop in an evolutionary way over a period of several years, and that the commercial feasibility of electric cars also would develop gradually. Thus, any electric vehicle production would be likely to be on a small scale at first and increase to a larger scale over a period of years.

However, if a "breakthrough" in battery technology leading to commercial feasibility is assumed, first production could be expected within the three-year lead time requirement discussed in answer to question #3.

It is assumed that an electric vehicle would be considerably different from existing vehicles and almost completely new tooling would be required. Once basic decisions about design had been made, plant and production engineering could proceed concurrently with the engineering design, and production could begin in about two years.

Mr. BROWN. Do you have a question, Mr. Blanchard?

Mr. BLANCHARD. Just a comment to Dr. Holzwarth and Dr. Agarwal.

I happen to also sit on a task force relating to the automotive industry, and I think most everyone in Congress has felt very frustrated with what appears to be the inertia that Congressman Ottinger referred to, and to some extent it's a frustration with ourselves, and with everyone, because we see so many new needs for our society, and there is a feeling that not everybody is doing as much as he can.

Now, you've seen some of that frustration expressed toward you today. I can assure you it's not intended to be directed at you personally, but simply at large institutions generally.

All of us on this committee are optimists. We want to know why not, instead of don't do something. We tend to talk and work with astronauts and people in NASA, and I think, from what I've seen with other committees, it's a very difficult role to represent a gigantic operation like General Motors because someone like yourself comes here with a specialty in one particular area, and you're expected, because you're the only ball game in town, to answer for the philosophy of everyone from the chairman of the board to an assembly line worker, which is like asking myself or Mr. Ottinger to explain why Earl Butz does what he does.

I want my colleagues to understand that you don't run General Motors. You're working in one special area.

And we also understand here, at least I do, that General Motors isn't in a position to focus perhaps as much attention, given the size of your company, to electric automobiles as we would like, perhaps as you would like since that's your specialty.

This bill, as I understand it, only authorizes, which is still a lot of money, about $40 million a year over a 3-year period to allow many, including General Motors, to further their work in an area we feel is important, and I guess we're looking for an answer to the question: Why not pass this bill? Why not proceed? Perhaps it's not a perfect bill in your opinion, but that's the question we really have. It's not: Is this bill perfect? but: Why not?

Mr. Holzwarth. May I answer that?

The way we understand it, Mr. Blanchard, the $40 million per year for 3 years is aimed at, or largely at, the building and construction of these demonstration vehicles, not for the R. & D. and for these other studies which we have said we think are important.

Our feeling is that after that money is spent we aren't really going to be any closer to the solution to the problem; we aren't going to learn any more from building 5,000 than if we were to build two or ten and test those, and test them thoroughly, and so why spend the $40 million when perhaps we can learn just as much from building two, or ten, or a dozen. We have 350 Post Office electric vehicles now.

But we come back to that same very basic problem, the onboard energy storage capability with existing technology, which in the near term just doesn't come close to doing the job. That's where the problem is, and that's why we think that public funding there would really pay great dividends.

Mr. Ottinger. Would the gentleman yield for a comment on that, Mr. Blanchard?

Mr. Blanchard. Certainly.

Mr. Ottinger. In the Commerce Committee we're considering energy legislation. The automobile manufacturers came before us and said that they could and, in fact, do produce internal combustion engines today that get 35 miles to the gallon. We said, "Why don't you?", and they said because there was no market for it.

There's no question that the companies respond to the demand that exists within our society. I think our effort here is to let people know that there are electric automobiles today that can serve limited purposes; can serve them quite adequately. As a matter of fact, in terms of acceleration problems in driving that you're talking about, the electric engine vehicles that I've seen have had equal or better performance, from zero to 30 miles an hour, at an intersection than most gasoline engines do.

So what we're trying to do is stimulate an interest here so that hopefully eventually the automobile manufacturers will respond.

Mr. Brown. Are you through, Mr. Blanchard?

Mr. Blanchard. Yes; I am.

Mr. Brown. Just one final question.

I am trying to identify how much of the expenditures that you have listed in attachment A might be considered as having been done on electric vehicles, or batteries, or related technology. I doubt if you have that broken out, but could you offer us a guess?

Mr. Holzwarth. No. I mentioned before, Mr. Chairman, that I did not have those figures with me, that in the electric vehicle development area I was quite confident it ran into tens of millions of dollars, and that I would submit a document covering that for the record.

[The material to be provided follows:]

Complete financial records that would enable us to identify expenditures by type of power source have not been maintained. The alternative power sources expenditures listed in Attachment A involve literally hundreds of different engines and power sources, and, of the $257,912,000, we estimate that $10 to $20 million represents research associated with electric vehicles.

Mr. Brown. If you would, we would appreciate that very much.

We have given you more of our attention perhaps than we should have this morning, and it has appeared to be critical, but if you think General Motors is unduly criticized, you should hear what people say about the Government as a whole.

[Laughter.]

Mr. Brown. I want to thank you, Mr. Holzwarth, and Mr. Agarwal, for your presentation, and hope we won't scar you irreparably, and we may invite you back sometime in the future.

Mr. Holzwarth. Thank you, sir. It's been a pleasure to be here this morning.

Mr. Brown. Our next witness is Mr. Frederic Sanborn, director of the ECOTEC Foundation of Cincinnati, Ohio.

We're pleased to have you here this morning, Mr. Sanborn, and without objection your full statement will be included in the record at this point. You may proceed to handle it in whatever way you wish.

STATEMENT OF FREDERIC R. G. SANBORN, DIRECTOR, ECOTEC FOUNDATION

Mr. Sanborn. Thank you.

What I would like to do is not read the statement. There are some points I would like to stress quickly, and then go into some other matters.

[The complete prepared statement of Frederic R. G. Sanborn follows:]

STATEMENT OF FREDERIC R.G. SANBORN
DIRECTOR OF ECOTEC FOUNDATION, CINCINNATI, OHIO
BEFORE THE HOUSE SUBCOMMITTEE ON
ENERGY RESEARCH, DEVELOPMENT & DEMONSTRATION
SCIENCE & TECHNOLOGY COMMITTEE
IN SUPPORT OF H.R. 6198
ON FRIDAY, JUNE 6, 1975

Good morning, gentlemen. My name is Frederic Sanborn. I am Director of the ECOTEC Foundation of Cincinnati, Ohio, a nonprofit, environmentally oriented organization concerned with the ways in which we use resources.

I will be speaking on behalf of ECOTEC, primarily to share with you our experience during the last two years with an electric vehicle program in southwest Ohio.

I am also speaking on behalf of Mr. Chandler Waterman, President of C.H. Waterman Industries of Athol, Massachusetts. Mr. Waterman could not be present here this week and has asked me to communicate to you certain matters regarding problems he has encountered as a manufacturer of electric automobiles.

My statement is divided into four parts. First, I would like to describe very briefly the ECOTEC electric vehicle project and the experience we have gained. Next I will speak on behalf of Mr. Waterman. Part three includes some views on the potential of electric vehicles, and I will conclude in part four with comments on H.R. 6198.

Before proceeding further, I would like to state my whole-hearted endorsement of the proposed legislation we are considering today. I regard it as a most important, timely, and perhaps historic bill. I would like to commend its sponsors and express the hope that it will be approved by this Committee, voted into existence by Congress, and implemented as quickly as possible.

I should perhaps add that the bill has a very special meaning for me. Two years ago in the height of my enthusiasm for electric automobiles, I pledged publicly not to purchase another internal combustion car. We have four licensed drivers in our family, with a fifth coming in August. Besides the electric car that we have been using for the past 24 months, we have a 1969 Ford station wagon and a 1969 Volkswagen bus. The Volkswagen is doing very well, thank you, but the Ford is failing. I am counting on you gentlemen to expedite this bill so that I may be saved from terrible embarrassment!

Part I: ECOTEC Foundation Electric Vehicle Experience

The ECOTEC Electric Vehicle Project dates back to the fall of 1972 when Mayor Berry of Cincinnati established an Environmental Task Force of citizen volunteers to study and make recommendations in five areas of concern.

One of these concerns was urban transportation systems and the role of the private automobile. ECOTEC presented testimony at hearings on this subject and proposed an electric vehicle demonstration project including automobiles, trucks, and buses, integrated with a public transit system. The proposal was received with interest. Time passed, however, nothing happened, and there was no local institution to follow through on our suggestions. It was apparent that ECOTEC would have to take the initiative if anything concrete was to be accomplished.

Accordingly, ECOTEC approached the local public utility, Cincinnati Gas & Electric Company, to determine whether it would undertake, or would support ECOTEC in undertaking, an electric vehicle program. We were aware that several years earlier CG&E had exhibited a variety of electric vehicles during a trade exposition in Cincinnati.

We were received courteously and soon received an answer. The answer was no, and for a reason that is important to the contents of H.R. 6198. The Public Utilities Commission of Ohio, in common with many similar regulatory agencies in other states, was increasingly taking the position that any action by an electric utility company that tended to promote consumption of electric energy, was not to be encouraged. Although CG&E was eminently capable of undertaking this project, it was unwilling to get involved with the commissioners who regulate it at a time when there were far more pressing issues at stake. I sympathize with the dilemma in which CG&E found itself. I hope that one of the first institutional factors to be dealt with under this Act will be the state regulatory agencies in Ohio and elsewhere.

Putting this incident in another context, we had run into our first institutional obstacle before even getting our project launched. Fortunately, there was an executive at CG&E with great personal enthusiasm for our project, Mr. George Peare III. During the past two years, Mr. Peare has given generously of his expertise, personal time, and sage understanding of the electric industry. We could not have achieved what we have without his support.

It was clear that for this project to take place, ECOTEC would have to fund it itself. Approximately $5,000 was allocated, and we began to look for a vehicle to purchase. Because of our limited funds, it was clear we would have to eliminate an electric truck or bus in favor of an electric automobile. Further, we felt that public interest would be greater in a car that might be within the reach of many Cincinnati residents. Our choice in the winter of 1973 was limited to less than six sources. We contacted manufacturers, studied their materials, talked with them by long distance telephone, and eventually selected a 1973 Datsun converted by C.H. Waterman Industries. I journeyed to Athol, Massachusetts, completed the transaction, was shown how to operate the car, and brought it back to Cincinnati.

In April, 1973, the Electricar, as we chose to name it, was officially welcomed to Cincinnati by Mayor Berry in ceremonies on Fountain Square in the center of the city. There was great interest, with a spate of newspaper articles, radio interviews, and TV film footage.

The car itself is a four-passenger, two-door Datsun using a 17-horsepower electric motor powered by 16 six-volt batteries that normally are recharged overnight. It has a range of 40 to 50 miles and requires little maintenance other than periodic addition of distilled water to the power batteries. It was originally manufactured, of course, as a gasoline vehicle. Waterman industries removed the gasoline engine and other internal combustion components, replacing them with the electric motor, batteries, and control system. The purchase price was just under $4,000.

The immediate objective of the ECOTEC project was to establish an enthusiastic base for electric cars in Cincinnati on which a broader program could be built. We had planned a program called the Daring Dozen, which, simply stated, looked to recruiting twelve individuals within the business and civic leadership of the city who would purchase an electric automobile either for their individual use or for their companies. Cincinnati is fortunate in having a considerable number of such people who value the city that sustains them and are willing to step forward in leadership roles in situations such as this.

Toward this end, we began exposing the Electricar in a variety of ways. We took it through the Cincinnati Safety Lane to obtain its inspection sticker. With us went the humorist of the morning newspaper, who writes a daily tongue-in-cheek column. He described the reactions of the safety lane personnel when they discovered they were dealing with an electric car.

We went to shopping centers such as the one shown in the reprint from Cincinnati magazine, which has been distributed to the Committee. We equipped the car with an audio cassette that described its functions and capabilities through loudspeakers placed under the hood and in the trunk.

The car was shown to a variety of groups, including high school environmental clubs, university students, a meeting of electrical contractors, and even to our resident astronaut, Professor Neil Armstrong. We told him that it was just like the lunar rover, except that it steered from only one end. I am happy to report that he drove it faultlessly on the very first try, and has since been a source of encouragement to us.

We then undertook to deal with various institutional factors. We sought to obtain special automobile liability insurance rates based on the premise that electric vehicles are inherently safer and less likely to become involved in serious accidents than cars powered by internal combustion engines. We suggested that the state sales tax include an exemption for electric cars purchased during the next five years. We proposed that a special Ohio automobile license plate would be appropriate. We began talking with lending institutions, suggesting that 4-year or 5-year financing would be appropriate for electric cars because of their extended life.

We began discussions with Queen City Metro, the publicly owned bus transit system that was just getting organized. We proposed use of one or two electric buses within the central business district where automobile pollution is the worst.

We also began to obtain a great deal of practical experience in operating Electricar within the hilly environment of greater Cincinnati. It would require an hour or more to relate the various experiences we encountered, so I will summarize them by saying that what we learned we could not have learned in any other way than through actual field trial. That is why we feel so strongly that the focus of this bill should be on getting electric cars out into public use as quickly as possible and in as large numbers as possible.

Just about the time we were ready to begin our Daring Dozen campaign, we received devastating news. A Detroit company that had long announced a high performance electric vehicle informed us that they could not deliver, due to the refusal of their American supplier to provide cars for conversion. Almost simultaneously, Mr. Waterman informed us that Datsun would no longer be importing the model he had been converting. He indicated that the Datsun that would be imported henceforth was not suitable for conversion and that he would have to find another vehicle. Other manufacturers were experiencing similar problems. In short, no one could deliver an electric automobile that would perform adequately on Cincinnati hills.

I should make clear that the reasons for this situation had little to do with electric vehicle technology. Instead, the problems were related to the deepening oil crisis and the sudden shift of public interest to the lightweight cars that were the best candidates for conversion to electric propulsion. Also, electric car manufacturers were having difficulty getting sufficient capital, setting up dealerships, receiving clearance from the the National Highway Traffic Safety Administration, and similar non-technical problems.

The only encouraging event was the formation in our community of the Noble Electric Car Company for the purpose of marketing electric vehicles. Its first project was the conversion of a Volkswagen Karmann Ghia, using a kit supplied by Hellectric, a manufacturer in California. The car was a great success and, after several months of demonstration, was sold. The Noble Electric Car Company also undertook to provide service on our electric Datsun and began looking for a car to sell in our market area.

Some months later, a Sebring-Vanguard Citicar was purchased by a local engineer. It has been in daily use by him while commuting to and from work.

ECOTEC took part in the Third International Electric Vehicle Symposium here in Washington in February, 1974. We have also undertaken various energy studies regarding the number of miles per kilowatt/hour our car obtains, plus ratios of peak vs. off-peak recharging. We made a number of modifications to our car and communicated these back to Mr. Waterman. He has incorporated some of them into his latest designs.

I would summarize our experience to date by saying that although we were successful in the sense of demonstrating a broad and deep interest in electric cars in Cincinnati, we failed in our more basic mission, which was to build a population of several dozen such cars so that the community could observe their performance and begin to consider alternatives to gasoline-fueled vehicles. Our failure, as I have already indicated, was the result of not being able to obtain electric cars at all during the disruptions of the Middle East oil crisis.

I would like to emphasize, therefore, that the bill under consideration here today is exactly the kind of legislation that will get programs such as ours off dead center and into speedy action.

Part II: Experience of Mr. Chandler Waterman

C.H. Waterman Industries is a small company under the direction of its founder and president, Mr. Chandler Waterman. Over the last several years, Mr. Waterman has produced and sold several dozen electric vehicles, the majority of which were Datsun

1200's converted from gasoline operation to electric propulsion.

As already described, the Datsun 1200 was no longer available in the United States after the late summer of 1973. Mr. Waterman then began looking for another imported car that could be converted to electric operation. One might ask why he did not consider converting a Ford Pinto, a Chevrolet Vega, or some similar "subcompact" American car.

The reason for this is made plain in a letter Mr. Waterman wrote to Senator Edward Brooke of Massachusetts on March 17 of this year. I quote:

> "Weight dramatically influences the ultimate efficiency of any vehicle. In order to obtain satisfactory performance on our electric autos, we have been forced to use imported vehicles which weigh a full 1,000 pounds less than the smallest so-called 'compact' U.S. car (1600 lbs. vs. 2600 lbs.). We have recently worked on two different European models in this weight range and find both to be fully as comfortable and drivable as any American small car."

A half-ton difference between a European compact and an American compact is a significant factor when converting to electric propulsion. Mr. Waterman goes on to recommend that Senator Brooke consider a weight tax on gasoline vehicles, beginning at the 1600-lb. level.

In the course of researching a variety of European and Japanese vehicles, Mr. Waterman found that the French Renault and the Dutch DAF were most suitable. Since neither vehicle is currently being imported into the United States, it was necessary to obtain a temporary exemption of certain safety requirements specified under the National Highway Traffic Safety Act.

On May 3, 1974, Mr. Waterman filed his first petition for temporary exemption, little realizing that 13 months later he would still be waiting for final approval. A month passed before he had a response from Mr. Richard Dyson in the Office of the General Counsel. There were phone calls, additional letters, delays, and confusion. June passed into July and August, and then into September and October.

In understandable exasperation, Mr. Waterman resubmitted his petition on November 2, 1974. There were further delays, telephone calls, and frustration, during December, January, and February.

Finally, on February 28 of this year, his petition was published in the Federal Register, which allows 30 days for comment. At the end of March he began following up by telephone and was repeatedly told that they were "very busy."

As of Friday last week, Mr. Waterman had not received clearance for exemption of his DAF's. Thirteen months have passed, and he is still unable to import cars or fill the orders he has in hand.

I relate this incident on behalf of Mr. Waterman as an example of the institutional problems in getting a new technology such as this off the ground. I would hope that this

Committee might invite Mr. Dyson to appear before it and explain why his office cannot process a matter of this sort in less than thirteen months.

Because of this kind of experience, I would urge that the bill we are now considering contain provisions to minimize the bureaucratic actions needed to get matters started.

For example, Mr. Waterman has the opportunity to begin manufacturing some of the components of the DAF in the United States. Indeed, it appears that, over a period of a year or two, he could obtain a license to manufacture nearly all the parts for his cars. In the process, he would be making engineering improvements. However, under the National Highway Traffic Safety Act, he would have to resubmit for safety clearance each time he made any significant change.

This kind of restraint seems unreasonable in the light of the low number of production units we are discussing. In fact, it could frustrate Mr. Waterman's desire to manufacture in this country.

Part III: Potential of Electric Vehicles

During the past three days I am sure this Committee has heard many of the reasons for further exploring electric vehicle technology. Among them are the shrinking availability of petroleum, the non-polluting aspect of electric vehicles, their energy conserving potential, their apparent greater safety, their greater durabilty, their increased cost effectiveness, and similar considerations.

I would like to mention three additional factors that I believe are important to the future of this technology.

(1) The use of electric motors to propel cars, buses, and trucks, opens up the possibility of a great variety of vehicles. This is so for the reason that electric motors do not cost nearly as much to design and tool as do internal combustion motors. I would point out to the Committee that the names of the American automobile manufacturers are the Ford Motor Company, General Motors, Chrysler Motors, American Motors, etc. It is significant that the word "motor" appears in the corporate name of each of these organizations.

As you well know, the expense of designing a gasoline engine assembly line is enormous. The consequence of this state of affairs is that an internal combustion automobile is built around its motor. That is to say, its basic characteristics of size, weight, wheelbase, and performance, are determined by the engine tooling investment of the manufacturing company. This practice, of course, discourages innovation in the form of ultracompact vehicles of the kind we see in the Sebring-Vanguard Citicar.

By contrast, electric motors are relatively inexpensive to engineer and tool, with the consequence that the vehicle can be sized to its mission instead of to its motor. This means to me that electric propulsion opens up the possibility of many different types of street vehicles designed for particular market segments and even for particular geographic areas. This I regard as a welcome change to the almost monotonous similarity of Detroit vehicles in terms of length, weight, passenger space, and the like.

At this point I would like to add a comment on the subject of the American automobile manufacturers based in Detroit.

First, I do not personally expect any useful response from Detroit in the area of electric propulsion technology. There are many reasons for this, of course. I am inclined to believe that the primary reason is that Detroit concentrates on stimulating public demand for the types of vehicles it finds profitable to manufacture. Be that as it may, it is clear that cars from Germany and Japan are far more innovative and flexible in their capabilities than their American counterparts. The imports are literally running circles around the American cars. And getting twice as many miles per gallon in the process.

Secondly, I would like to bury the myth that one job in six depends on Detroit. This is pure nonsense. It is repeated by spokesmen for Detroit in an effort to intimidate.

I recommend to the Committee some recently completed (but as yet unpublished) research by Mr. Harold Sutcliffe of Mackay Shields Economics, 551 Fifth Avenue, New York. Mr. Sutcliffe investigated this one-job-in-six claim with great care. The highlights of his research are as follows:

1) The automotive industry ranks fourth among all American industries, behind construction, food, and health care.

2) Direct employment of the Detroit automakers was approximately one of every 121 American workers in 1973-74.

3) If we include non-automotive workers such as the steel and rubber industry suppliers to automobile manufacturers, the ratio increases to one job out of every 63 (or 1.5%).

4) In the worst-case projection that Mr. Sutcliffe could reasonably imagine for the year 1980, the decline in automotive employment would be less than 0.3% (1/3 of 1%) of the then projected labor force of 100,000,000 workers.

In short, the time has come to puncture this particular balloon, not to mention the economic doomsday it appears to suggest.

Instead, let's challenge Detroit to build the most gas-efficient vehicles the world has yet seen and make them as safe and durable as 1975 technology and materials permit. While the big three are busy with this challenge, let's proceed with your Committee's program to put 5,000 or 10,000 (or, better yet, 50,000) electric vehicles in use so that we can begin to appraise an alternative technology both technically and in the marketplace.

(2) A second exciting potential of electric vehicles is the possibility of their integration into transportation networks in the future. Several possibilities come to mind.

First, an urban electric car such as the Sebring-Vanguard Citicar is compact enough to fit comfortably on an intercity railroad train such as those being operated by Amtrak. In Ohio, the State Capitol, Columbus, is 110 miles from Cincinnati. Our Senator Robert Taft has been working to obtain Amtrak service from Cincinnati to

Columbus (and Cleveland, Toledo, and points beyond). For those of us living in Cincinnati, it would be ideal to drive our electric cars to the Amtrak station, load them onto a flatcar, relax in the passenger section while the train moves to our destination at 100 mph, and then have our own personal transport available at the other end.

This car-rail combination is already in operation between Ohio and points in Florida. Electric cars are so much more compact than gasoline cars, that many more would fit on a single flatcar and could be more easily loaded and unloaded.

(2) A second possibility for the future is the development of "powerpods." By "powerpod" we mean a small two-wheeled trailer that could be rented from Hertz, Avis, U-Haul, etc., on those occasions when the electric car owner wished to travel an extended distance over existing highways. The powerpod would consist of an electric generator driven by a heat engine, initially fueled by gasoline. The generator would supply continuous electric power to the automobile, thus conserving its battery charge. If there happened to be a pollution crisis in a city along the way, the powerpod could be turned off and the electric car would proceed through the city on its batteries.

When the trip was over, the powerpod would be returned to the rental agency. Thus the electric car owner would be spared the expense of having to own or rent a second, gasoline-powered automobile for trips away from his home city.

(3) A third potential of electric vehicles is their ability to be integrated with all conceivable energy systems. Electric power can be obtained from coal, hydro, geothermal, wind, solar, solid waste, and even grass cuttings and leaf rakings. By contrast, oil comes from the ground and, once used, is gone forever.

Most exciting of all is the potential of electric vehicles to be integrated with home energy systems during the next decade or so. A house that is "wired" to the sun by means of solar collectors can supply not only heating, cooling, and domestic hot water, but electricity as well. We have the technology to store some of this sun-generated electricity so that our electric cars can be recharged at home at the end of the day.

Part IV: Comments on H.R. 6198

As suggested at the beginning of this statement, we are heartily in support of the timing, intent, and scope of this bill. In the comments that follow, I would like to urge some changes in emphasis and approach that would, I believe, make the proposed legislation even more effective.

The first observation I would make is that the American people may be a great deal closer to accepting electric cars than is realized by the individuals who would be administering this bill. Time and again I have been asked where an electric car like ours can be bought. Nearly everyone who has seen our car and thought about it has made a comment such as, "It sure makes sense," or "That's the way to go."

In short, we feel H.R. 6198 should focus more heavily on making electric vehicles available to as many people as quickly as possible. Indeed, we believe that there are enough people ready to try electric cars that only a modest subsidy would be needed to get the electric vehicle industry moving.

Specifically, we suggest that a subsidy of $2,000 be paid to electric car manufacturers for each of the first 5,000 vehicles they individually deliver to paying customers. A direct subsidy such as this has various advantages over any other form of underwriting that we are aware of:

(1) The manufacturer is encouraged to produce and deliver as quickly as possible.

(2) The subsidy can be used any way the manufacturer pleases: for example, to absorb some of his tooling and startup costs.

(3) The manufacturer is free to produce his car in the form he feels will make it most saleable to his intended market.

(4) The manufacturer is encouraged to move ahead with developing a dealer sales and service network.

(5) There is no need for a lottery to determine who shall receive the first electric cars. Instead, customers are self-selecting, according to their willingness to pay for an electric car. Thus we use the traditional market mechanism.

(6) The government is not involved in the specification, purchase, or use of electric cars, a business that it is not equipped to undertake. If a local, state, or federal agency wishes to purchase a vehicle, it can do so just like a private citizen, taking advantage of the $2,000 manufacturer's subsidy.

(7) The true test of electric vehicle technology is whether or not the public will accept it. The manufacturer's subsidy approach will determine that question quickly.

(8) Assuming, as we believe, that the public is responsive to electric vehicles, the subsidy will lay the basis for a healthy industry with (a) a variety of vehicles, (b) field experience to show the merits and problems of each, (c) dealer service networks in being, and (d) a start toward solving infrastructure and institutional problems.

The subsidy approach would also be able to purchase a great deal more electric vehicle production and experience with the $160,000,000 appropriation that is contemplated. Yet no one manufacturer would receive more than $10,000,000, nor would he have it until he had actually produced and delivered 5,000 vehicles.

Thus the number of vehicles specified in Section 4(4) could be increased from 5,000 to perhaps 50,000.

Section 7(c)(1), which contemplates introduction of electric vehicles into state, local, and federal government agencies, might be unnecessary. Indeed, we believe it is much more desirable for these vehicles to be in the hands of public citizens and private companies such as electric utilities, local telephone companies, municipal bus companies, and the like, than in governmental units.

What counts is public experience. If the Army Quartermaster Corps purchases 100 bakery vehicles in olive drab, a commercial baker is unlikely to be impressed. He will likely assume that the Army experience is different from his own. But if 24 commercial bakeries around the country purchase, use, and recommend electric trucks for use on urban delivery routes, he is much more likely to take notice and do likewise.

We see no harm in a government agency participating in the program, but not for the purpose of seeking to develop public acceptance and credibility.

As we see it, the need is to do everything possible to encourage the early production and use of electric cars, trucks, and buses, so that the flow of vehicles into the marketplace can begin.

For this reason, we believe that the requirement of Section 7(b) that the administrator develop performance standards and criteria within six months, is unwise. We also recommend against the provision of Section 7(a) (1) that vehicles purchased during the first year meet these standards.

Waterman Industries, Sebring-Vanguard, and other companies are, or shortly can be, in production of quite adequate electric automobiles with ranges that are suited to the duty cycles of many individuals and organizations. For a government administrator to attempt to put together at this time some arbitrary set of performance standards would not only be difficult, even if possible, but would further delay an infant industry that no one seems willing to allow to grow up.

We agree that it is necessary to protect this program against manufacturers who might try to sell unsatisfactory vehicles. The way to discourage this, we believe, is not by some all-inclusive government specification. Instead, H.R. 6198 can provide that the manufacturer must publish his own specification (the content of which can be outlined by the bill) which every production vehicle must meet. If his vehicles fail to meet his specification, he must replace the customer's car with one that does, or refund the original purchase price.

By this means, the prospective consumer can decide whether the performance of a particular vehicle meets his need and expectations. The government does not belong in that business.

I should perhaps point out that guaranteed performance specifications for electric cars will mark a breakthrough in consumer protection in the automotive field. Did anyone on this Committee ever hear of Detroit offering a performance specification?

The second priority under H.R. 6198 should be the reduction and removal of institutional factors that delay the production, sale, and use of electric vehicles. The experience of Mr. Waterman in seeking to obtain a variance from the National Highway Traffic Safety Administration, is a glaring example of this. What is needed are incentives to:

(1) Encourage insurance companies to reduce insurance rates on electric cars.

(2) Encourage lending institutions to extend time payments for electric vehicles to 48 or 60 months (instead of the customary 36) so that monthly payments are at levels that will encourage the consumer to try electric cars.

(3) Encourage state and local governments to waive sales taxes on electric cars

for a period of five years. While the legislatures are working on this, buyers could receive cash refunds of sales taxes paid. The refunds would be provided by the administrators of this bill.

(4) Allow companies purchasing electric vehicles to depreciate them totally over the first three years as an incentive to buying them now.

(5) Enable electric utilities to participate in the electric vehicle program without censure from state regulatory agencies.

(6) Exempt powerpods from emission standards for the first three years in order to accelerate the development and testing of that concept.

These are examples of many specific institutional changes that are needed if this program is to get moving rapidly.

Turning now to the subject of research and development, we have a concern that substantial funds will be spent on projects that will not bear fruit in any reasonable near term. Again, I cannot emphasize too strongly the need to do our research in the marketplace, using the actual experience of people and institutions with particular electric vehicles.

Thus, with respect to Section 6, we would recommend that: (1) not more than $6,000,000 be spent on research and development (5% of total funding), and (2) that these funds be spent on projects recommended by the manufacturers of electric vehicles themselves. To implement this provision, an Electric Vehicle Manufacturers Council should be specified in the bill, which would prioritize proposals for R&D funding. This concept is similar to that of "peer review" that has long been used by the Department of Health Education & Welfare in prioritizing research grants in the health sciences.

Further, we recommend that the provisions of Section 5(c) (2) that require the administrator to determine "optimum overall electric vehicle design," should be deleted. To begin with, there is no such thing as "optimum overall electric vehicle design" any more than there is for internal combustion vehicle design. And even if there were, I doubt that the administrator would discover what it was in the absence of significant field experience. Provisions such as this will only serve to create uncertainty, doubt, and delay.

Instead, the bill should make provision for determining customer needs and desires. This can best be accomplished, in our opinion, by establishing an Electric Vehicle Consumer Council that will serve as a consultative arm of the administrator of this act. The Council should include individual owners, representatives of electric vehicle associations, and staff from consumer testing organizations that are industry independent. This Council, with the aid of appropriate field interviewing techniques, can quickly develop a valuable body of consumer experience with the electric vehicles produced and sold under this program.

Finally, we recommend that Section 5 of H.R. 6198 be modifiend under Subsection (c) so that the priorities listed there be in the following order:

(1) Conducting demonstrations of electric vehicles.

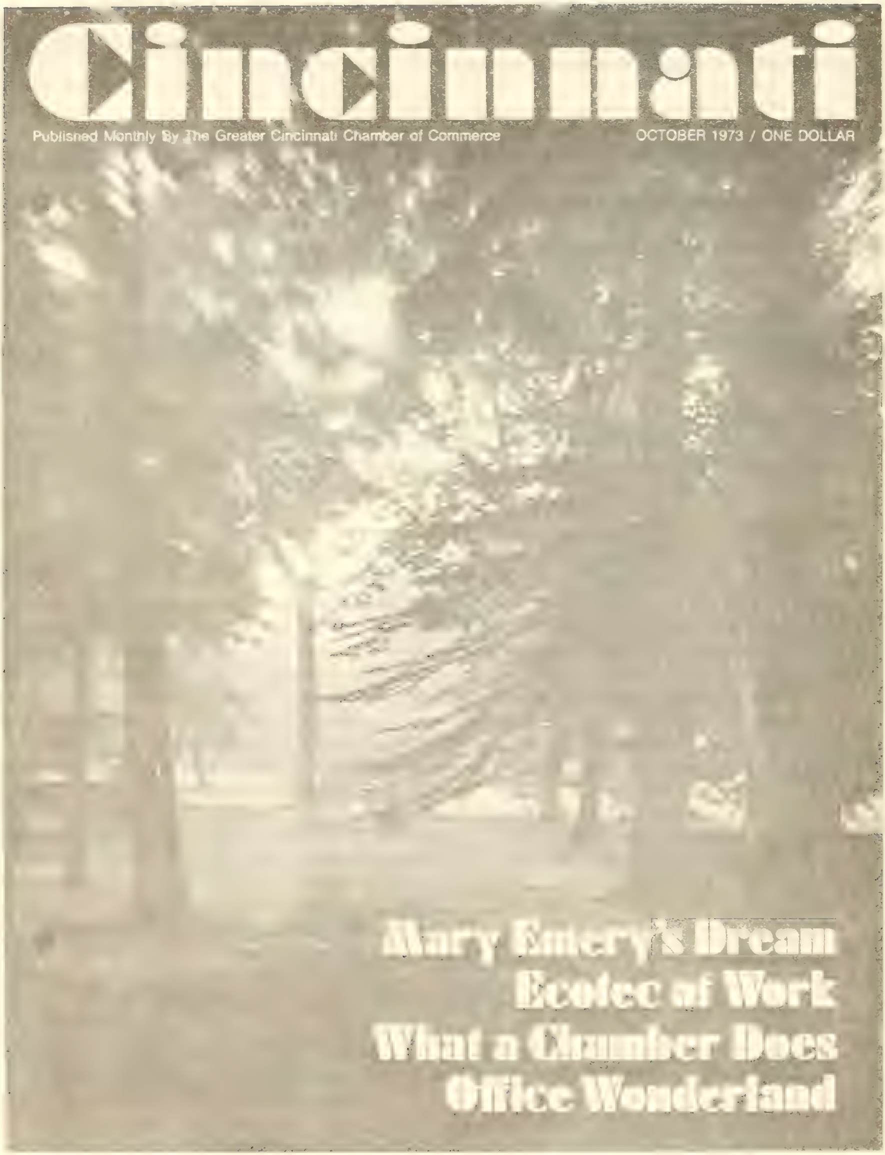
(2) Ascertaining the long-term changes in.... (various institutional arrangements).

(3) Ascertaining consumer needs and desires (as already proposed above).

(4) Promoting research on electric vehicles (again, as recommended above).

In short, we urge the Committee to modify the bill so as to encourage the maximum production of electric cars, trucks, and buses at the earliest possible moment, with the evaluation being performed by the buying public based upon actual field experience with these vehicles.

Thank you.



Cincinnati

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Mary Emery's Dream
Ecolec at Work
What a Chamber Does
Office Wonderland

Dreamers become doers

Ecotec and the electric car aim for a livable future

Lift the hood on an electric car (upper left), and you'll find none of the usual air polluting gadgetry. Lower left, the Pedicar is a prototype for future bicycling. This model is self-propelled for neighborhood runabouts, but future designs may be battery operated. At right, an electric car generates interest wherever it goes and requires only a normal household outlet for recharging.

Tired of reading of waste and want? Of the gas shortage, the food shortage, the energy crisis? Of problems with the pipeline, pollution, population? Then you'll want to read about Ecotec Foundation, for it was out of frustration with our too little-too late solutions to environmental difficulties that the Cincinnati organization came into being.

What is Ecotec? Who are its members? How does the group plan to effect change?

Organized in March 1972 as a nonprofit Ohio corporation, Ecotec Foundation attempts through education, research, experimental or demonstration projects to find grass-root solutions to our environmental hang-ups. Participating members (individuals or organizations) pay annual dues of $25.00 or $5.00 plus 20 hours of service.

Co-founded by practical visionaries, F. Peter Seidel, architect-planner, and Frederic R. G. Sanborn, businessman-environmentalist, the organization is now governed by Seidel and Sanborn and five additional trustees: Esther Gaunt, former Cincinnati area president of the League of Women Voters, Stanley E. Hedeen, associate professor of biology, Xavier University, Lawrence Welsch Kessler, associate professor of law, University of Cincinnati; Judith M. Schultz, assistant professor of biology, University of Cincinnati; and Robert L. Steiner, former president of Kenner Products, Inc. Currently 400 interested people in the area are being solicited for membership.

In his book-lined office in his home

TEXT BY RUTH ENGELKEN PHOTOGRAPHS BY CORSON HIRSCHFELD

REPRINTED FROM CINCINNATI MAGAZINE

This model community (below) makes efficient use of land and is loaded with innovative features . . . such as (right) scale model homes with roofs that absorb solar rays for heating. Below right, Ecotec's van takes environmental shows "on the road."

on DeMar Road, dark-haired, dark-eyed Fred Sanborn, president of GROWTH Systems (a firm specializing in communications networks) is eager to talk about Ecotec. "We are institutional change agents rather than individual ones. Our philosophy is that people, given the opportunity to make a free choice, will make one that in our value system is wise."

As Sanborn sees it, the task of Ecotec is to offer wise alternatives; hence, their Electric Vehicle Demonstration Project, organized this year as Phase I of a three-phase program which will later evaluate electric trucks and buses.

The project grew out of Sanborn's testimony before the Environmental Task Force last December on alternatives to the gasoline car. "It suddenly struck me: 'How in the world are we ever going to get an electric car? Detroit isn't going to do it. I felt the quickest way — possibly the only way — to get started was for our organization to come up with a program." The red Datsun, converted to electricity and parked in his driveway, is his dream magic-wanded into reality.

The car, costing about $4,000, has zero emission, a top speed of 50-60 miles per hour and a distance potential of 50 miles between charges. The battery can be recharged from an ordinary outlet when the power demands are lowest at night.

Demonstrating the durability of electric motors was Darrell Harper's sixty-two-year-old Detroit Electric displayed by Ecotec on Fountain Square last spring. The car still runs on its original electrical control system; only the batteries and tires have been replaced and the body repainted.

"Ultimately electric cars will be built as electric cars from the ground up; they will be built differently," says Sanborn. "Right now we have a hybrid — a car with the gasoline motor taken out. That is not the best way to do it, but it is a way to get started and a practical way to keep the cost down." Driving the car has been a learning experience for Sanborn who finds the gearing needs modification for Cincinnati hills.

To focus attention on electric vehicles, Sanborn hopes Chandler Waterman, who electrified the Datsun, will transfer his operation from Athol, Massachusetts to Cincinnati for six months or a year. It takes only 1,000 square feet or so of factory space and 20 man hours to convert a car.

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Sanborn, who is committed never to buy another gasoline car, (he will replace his four with electrics) feels that ultimately Detroit must change; they cannot go on turning out gasoline cars. He commends the inter-industry cooperation found in Germany where Volkswagen is working with A.E.G. (the equivalent of G.E.)

"When we reach the stage of electric vehicles, our expenditure for personal transportation as a percent of our Gross National Product will go way down because we'll buy a car and run it 20 years — which may be one reason Detroit doesn't want to touch it. That's the kind of thinking we must change."

They must change, too, designs of all kinds. The "unsafe, antiquated, inefficient" bicycle, for instance. "We want to get some funding to develop about 20 prototypes of what we feel would be a safe commuter bicycle." It must be lit, have brake lights and signal indicators. They would demonstrate the prototypes; but, more important, they would change the thinking of the manufacturer.

To further stimulate innovative thinking, the Foundation hopes by next spring or summer to get funding to take about 20 Cincinnatians in key positions (City Council, the City Manager, people from the Chamber of Commerce, cameramen from WCET, etc.) on a tour of European cities similar in size to the Queen City. Sanborn, who spent many years in Europe writing tour books for Fodor, knows of effective transit and traffic approaches being tried overseas.

As a native of Brooklyn, he is a firm believer in public transportation. "Don't tell me it's impractical; I was raised in the subway. It ran 24 hours a day, 7 days a week, 365 days a year. Now it costs 35¢, and it's still a bargain."

The Foundation is also interested in community planning, a topic about which Peter Seidel, who formerly taught architecture at the University of Michigan, is knowledgeable Seated in the rocker in the living room of his three-story buff brick on Wold Avenue, sandy-haired Seidel — whose earnest blue eyes sparkle above his Vandyke beard — stresses the need for a broad approach to our problems.

'If we really look at all the problems we have today — the crime, the wrecking of cities by running freeways through them, the inner-city housing problems, the traffic congestion — they are all consequences of real efforts to improve ourselves. We have really been trying to make the world better for mankind. But the side effects of many of these things we have tried to do have been negative.

"We can't continue to go on this way and every time look at the small fragment of things — like the exhaust pipe on the automobile, not considering at all what it's doing to the fuel consumption of the automobile, nor considering how it's going to affect the whole manufacturing industry; these whole things are systems that are integrated and we have to think of them this way."

This transplanted Milwaukeean, who received his graduate degree from Illinois Institute of Technology and worked with the chief architect of the John Hancock Building and the Sears Building in Chicago, believes in common-sense solutions.

"The most wonderful way to reduce pollution is to reduce consumption of energy. The things that we are doing now actually increase energy consumption. . . . We know that we can build houses that could easily use about half as much energy to heat them; they could be kept reasonably comfortable without air conditioning or we could air condition them at about half the energy now going into air conditioning a house.

To prove that innovative systems can work, Seidel cites the unique heating and cooling method developed by Dr Clarance A. Mills, emeritus professor of experimental medicine at the University of Cincinnati. The coils in his Clifton home absorb body heat, allowing him to feel cool with a much higher air temperature

Seidel himself is busy planning a model EcoCommunity in Clermont County which will have a man-made lake, a variety of houses, hiking and riding trails, a community building, and novel ecological features. He is convinced he can provide better amenities on less land by using land more efficiently. While this EcoCommunity is not an Ecotec project, it is the type of thing Ecotec encourages.

Pragmatic Seidel takes a Janus-view at progress. His backward-forward glance projects the best from the past into the future. "There are a lot of things that people did a hundred years ago that we have forgotten. All sorts of things. Some things that we know about mathematics will consume less energy; for instance, we can reduce the exterior surface of the building." Also, we need to relearn about cross-ventilation and that how a window is opened determines the direction of a breeze. Centuries ago Socrates knew that houses should face south.

In his attic office, Seidel displays models and exhibits which incorporate his enlightened concepts.

In parting, Seidel cautions, "We wait until the symptoms get so bad, then we work on the symptoms. We've got to work on the roots and look ahead to avoid the problems."

That's what Seidel and Sanborn and Ecotec are trying to do.

ECOTEC FOUNDATION

ECOTEC FOUNDATION • 2923 WOLD AVENUE, CINCINNATI, OHIO 45206 • (513) 861-8324 • TO FURTHER THE INTEGRATION OF MAN, NATURE, AND TECHNOLOGY INTO ECOSTABLE LIVING SYSTEMS THROUGH RESEARCH, DEVELOPMENT, DEMONSTRATION, EDUCATION, AND ADVOCACY OF CONSTRUCTIVE CHANGE IN RESOURCE UTILIZATION.

CHW ELECTRIC AUTOS

Model 886 Two Door Sedan

The CHW four passenger electric sedans are engineered for practical, low cost urban and short run driving. Operating solely on battery power they produce no air pollution and require only a fraction of the maintenance of conventional autos. All models have independent front suspension systems with drum brakes, automatic vari-speed transmission, bucket seats, fully instrumented dash, four way safety warning flashers, safety lights, windshield washers, vinyl upholstery, lap and shoulder harnesses and innumerable other creature-comforts.

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Why not drive a CHW today and be one of the first to experience what is surely in everyone's future — pollution-free electric transportation?

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Nothing beats electric vehicles for economy of transportation. The slightly higher cost is quickly offset by the fractional cost of operation both in fuel savings and much reduced maintenance charges. Imagine an automobile without mufflers and exhaust system, radiator and cooling system, spark plugs, carburetor and fuel tank and you quickly get the picture of a simple, easy-to-maintain vehicle. That's what the CHW Electric is all about; with only one moving part in the power plant and a once-a-year check of the the motor brushes the only important electrical concern you have the essence of carefree economical driving.

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	886	887
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Width	61″	61″
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Tandem type hydraulic, drum.

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Motor—48 Volt DC, traction.

Power Source—Sixteen 6 volt electric vehicle batteries.

Speed Control—Three step, foot operated.

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Acceleration—0-25 MPH 15 seconds.

Range—To 50 miles standard. 80 miles with additional battery pack.

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Mr. Sanborn. The organization I represent is an environmentally oriented group. To that extent we represent what might be called consumers, or, hopefully, the future consumers of the fruits of this legislation, which we heartily support. We are perhaps different from others who have testified before your committee in that we have a point of view which we feel very strongly about, but we have no self-interest to promote.

I will also be speaking on behalf of Mr. Chandler Waterman, who is an electric vehicle manufacturer, because I am familiar with his situation and feel it is germane to this legislation.

I would like to express my dismay both as an American and as a consumer at the testimony we've just heard. I think it is a great shame that in this country, which does indeed represent a free enterprise economy in many respects, we find this kind of response.

As the committee may be aware, in Germany we have the example of several major automobile manufacturers, including Volkswagen and Mercedes-Benz, working in a consortium with one of the major electric companies—which in this country would be the equivalent of General Electric—and together with a major utility as the source of electric energy, working in concert to test these concepts, to build vehicles, and so on. I would wish that we might have this paradigm in our country.

I feel as though we have a third presence here, maybe an invisible third presence, sitting over on that side of the room, representing the Detroit companies.

I would like to comment just a little bit on some of the experiences we've had with our electric car.

I'm sure you're familiar with the story of the bumblebee who, according to aeronautical engineering principles, could never get off the ground. I feel somewhat like a bumblebee who's been flying 2 years with an electric car. I'm here to tell you that it works. It gets us from A to B and back quite comfortably.

I would like to make one immediate response to almost the last comment of the previous speaker. He said he felt we could learn as much from 2 or 10 vehicles as we could from 5,000 or some larger number. I would totally disagree with that for many reasons. Most particularly I think the whole institutional side of our transportation system is just as important, if not more so, than the technology that turns the wheels. I would like to give an example.

In my written testimony I refer to our foundation going to Cincinnati Gas & Electric Co., for support, as the first logical source of help for a local effort. In times past, like other utilities, C.G. & E. has promoted electric refrigerators, electric air conditioning, clothes washers, and all of the appliances we now take for granted. However, they did not feel free to participate in our activity, whose purpose was the same as this committee's: To get electric vehicles out in actual use. Our goal was 25 cars in private hands over a period of 2 years, so that people as consumers would have the opportunity to slam the doors, kick the tires, experience it through the seat of their pants and say, "Yes, we want it," or "No, this is terrible."

I don't think those of us sitting in this room can speak for the whole American people on this technology. We have to get out and experience it. It's a vast country, from hot, flat areas, to cold, hilly areas. There are many, many duty cycles, retired people to people with families of 12, and so forth, and everything in between.

So our goal in Cincinnati was the same as that of this committee, to get the vehicles out. However, because of the public utility commission in Ohio, which I understand is typical in many in this country, C.G. & E. felt that any effort by them to get really involved in promoting electric transportation would be viewed as contrary to utility commission policies because it would appear to be promoting the consumption of electricity at a time when we are more and more concerned about conservation.

I totally disagree with that point of view. This legislation, if passed, could have a very important impact on such policies. Indeed, I would hope that the bill would address this problem and provide that regulatory commissions at the State and local level encourage utilities to experiment with electric vehicles.

There are many reasons for this. For example, we are proposing recharging stations as part of parking areas. Cincinnati Gas & Electric Co., provides street lighting in the city of Cincinnati under contract. Since electric power goes to the street lights, they would be logical places to provide recharging stations. However, under utility regulations, it is illegal to "retail" electric power. The city of Cincinnati, paying for that street lighting, cannot sell electric power to me as a driver of an electric car at 10 cents a kilowatt-hour. That's called retailing. This is another example of an institutional factor which has to be changed. The city could charge me for parking and throw the electricity in free, but they couldn't charge me for the electric energy directly.

These are examples of institutional factors, which I strongly believe getting 20,000 electric cars or more is going to force us to consider and deal with. If we fail to do this and wait 3 years, all of that business is going to be ahead of us still, and people will say, "Where can I plug it in?" "Where can I get power?"

I've been talking with a gentleman this morning from the American Automobile Association. He's concerned about what happens when I call him on AAA membership, and say to him, "My car won't start," and he says, "Battery trouble?" and I say, "Yes, I've got 16 of them." These are all things that have to be dealt with, and the sooner we start, the sooner we will have solutions.

Just as another comment here, in the course of obtaining our electric car, we stopped by Consumers' Union, which is based in Mount Vernon, N.Y. They have an automobile test facility in Orange, Conn. We stopped by and let them test drive our car. It was not the normal kind of test for the purpose of publishing a report, of course. But it was the first time anyone on their staff had seen an electric car, much less driven one.

Thus, I would like to propose that the legislation resulting from these hearings includes consumer groups that can give some public reaction to electric vehicles, as well as industry groups and others.

Another very important reason for getting quantities of electric cars on the road as quickly as possible is the kind of practical experience that we as consumers get with them. I mention in my written testimony that we've learned a great deal during the 2 years we've had our electric car.

One of the things we have learned is that when you blow a fuse on an electric car, according to Murphy's law, it will happen in the worst possible situation. I've stood with rain pouring down my neck in the middle of a construction site, with cars splashing water on my trousers while I tried to change a fuse located under the hood. When this happens, you're likely to feel there's got to be a better way. And there is. We installed a bypass switch so that when a fuse blows, you can get out of the traffic and change the fuse under a dry roof. These are the things we learn from actual experience.

Another example. Our car has regenerative braking. We hardly use the mechanical brakes, because when we want to slow down we simply set the speed control to a lower voltage, and the car slows down very responsively. This creates a problem for cars following us who are used to seeing a taillight come on when the brakes are applied. Especially at night this is a problem, because our depth perception is worse at night, and a rear end collision could result.

Electric cars, I feel, should have some types of inertial device that will illuminate what otherwise would be the brake lights when they're slowing down regeneratively.

These are examples of things we're going to find out only through practical experience, and not by someone sitting in a room and gazing at the ceiling.

Getting back to the bill we're considering this morning, the focus should be, in my opinion, on getting as many electric cars out in use as quickly as possible, and in the hands of private individuals.

In terms of our experience off-peak versus on-peak, I would point out that we have installed special electric meters at the location where our car is usually recharged. One meter measures all the electricity that goes into the car, and the other measures that portion which is taken off-peak between 9 p.m. and 6 a.m. Our experience is that about three-quarters of the energy we take comes off-peak.

The range of our car is quite adequate for the missions it performs, so we don't normally have a requirement for daytime recharging. Other people, of course, will have different use patterns.

I would like to turn briefly to the experience of Mr. Chandler Waterman of Waterman Industries in Athol, Mass.

Does the committee have copies of this brochure?

I'm discussing the product shown in the brochure. This is a product Mr. Waterman had hoped to have available for sale to the public at least a year ago.

I would like to address two considerations.

First, why is Mr. Waterman using an imported car? The car you see there is manufactured in Holland. It's a DAF automobile.

Mr. Waterman wrote to Senator Brooke of your sister chamber, and said:

> Weight dramatically influences the ultimate efficiency of any vehicle. In order to obtain an acceptable performance on our electric autos, we have been forced to use imported vehicles which weight a full 1,000 pounds less than the smallest so-called "compact" U.S. car (1,600 pounds versus 2,600 pounds). We have recently worked on two different European models in this weight range and find both to be fully as comfortable and drivable as any American small car.

And this is still true. The car we have, which began as a 1,600-pound car, and now weighs about 2,400 pounds because of the additional batteries, still weighs very significantly less than any American compact car, be it a Pinto, a Vega, or whatever.

The speaker who follows me is also using an imported car, the Renault.

The other thing I'd like to call your attention to is that Mr. Waterman has been waiting for 13 months now to get clearance from the National Highway Traffic Safety Administration for his car to be imported and sold. He has orders; he has deposits; he has built and tested protypes over a period of 18 months; but he is not free to deliver his cars.

I would hope that Mr. Richard Dyson, who is handling his case, would be called by some member of the committee and asked why the inexcusable delay.

I would submit to you that——

Mr. HECHLER. Mr. Sanborn, do you have any idea why?

Mr. SANBORN. I have several ideas, sir, but they're uncomplimentary to the Federal bureaucracy.

May I say this, and I precede it by saying that both of my parents were lawyers. I think part of the problem is that Mr. Dyson is an attorney, and attorneys are not engineers; they're not familiar with electric technology. Apparently, Mr. Dyson has kept finding more and more questions to ask about this Dutch car.

Mr. THORNTON. Would the gentleman yield?

Mr. HECHLER. Certainly. Go ahead.

Mr. THORNTON. The Dutch car has some technical features which have been the reason that it is no longer imported into the United States. It was imported for a time. Among them are that it does have a fully automatic transmission, infinitely variable, from a ratio of about 2.6 to 1 to 17 to 1. The only gear shifting is either forward or reverse, and, therefore, this does not comply with standards for transmissions which have been established by the Federal Government.

The frame and chassis also fail to comply in some detail with the safety standards which were promulgated a few years ago. The car was being marketed on a limited basis. It was decided to take it off the market for those reasons.

I feel confident that the reason that the exemptions are not being obtained is because of the safety standards for the Dutch manufacturer on the frame and chassis, which has no structural members. It's a body-shell-type frame. It's very satisfactory, but it doesn't meet some of the safety standards.

Mr. HECHLER. Would the gentleman yield at that point?

Mr. THORNTON. Yes.

Mr. HECHLER. It seems to me if what the gentleman from Arkansas indicated is true, that Mr. Dyson ought to have the courage and honesty to come out and say it, instead of sitting around for 13 months and giving somebody a runaround on it.

Mr. THORNTON. I'm not familiar with the details of the case, but I'm quite familiar with the car and with the drive train. It does happen that this was the engine and transmission which was used in a project where the frame-chassis, et cetera, were manufactured here in this country a few years ago, and the car was imported for a time.

Mr. SANBORN. I would agree with Mr. Hechler. I believe it's a problem that could be communicated by telephone or some other form.

I would add to that that if the car is approved I believe there should be different safety standards for electric vehicles, because they don't go on the highway at 80 miles an hour, and there are many things they don't do that internal combustion powered engines do.

Let's assume that the car is accepted. A further problem that Mr. Waterman faces is he has been encouraged by DAF to import components when he gets into volume production. He believes he can manufacture the chassis in this country. He would like to buy American, but when he does so, he will be making engineering changes, and then he will have to go back through the whole approval cycle again.

I would like to point out to the committee that the great majority of cars on the highway today don't meet Federal safety standards because they were manufactured before the standards were promulgated. So I think we have a problem here that needs to be addressed.

I'm not an engineer, and I don't have the expertise to make specific recommendations, but I think there should be separate safety standards for electric vehicles.

In this context I would like to suggest that the legislation could perhaps include the concept of "National priority status," for new technologies. Solar energy would be another example of a technology which I believe the committee would agree is vital to this country's future. We need a legislative means of expressing these priorities in preambles to legislation, so that existing administrative and regulatory agencies must respond within a certain time period. For example, if there's any objection they've got to get back within 30 days, or that's their last opportunity to intervene.

Clearly, we don't want to circumvent the administrative process, except in an emergency situation, but I'm sure if we were at war we wouldn't put up with this type of delay.

I'd like, then, to turn to some of the potentials of electric vehicles, and comment especially on the unseen presence of Detroit.

I would ask you to note that the companies in Detroit all have the word "Motor" in their names: General Motors, Ford Motor, American Motors, and so on. This is no accident.

The biggest automotive tooling expense, of course, is for an engine line. There's a tremendous cost associated with that. A secondary consequence of it is that cars are built around their motors, because of the weight, the horsepower, and other characteristics.

With electric vehicles, we circumvent all of this misplaced emphasis. Tooling for electric motors is much less costly than for gasoline motors. There are far fewer parts. They're easy to fabricate. And, most important, an electric motor can be tucked away in different places.

So one of the things that is clouding the issue—and I think the testimony we've just heard would be an example—is that we're comparing gasoline cars of a certain weight with electric cars, assuming that the weight of electric cars is going to be equivalent. That simply isn't true.

Mr. Beaumont, who addressed you yesterday, and another manufacturer, produce cars that weigh a little over 1,000 pounds. That is a ton and a half less than a Vega or a Pinto. So when we can put in a 3-horsepower, 8-horsepower, or some other small electric engine, we have the flexibility of designing vehicles to particular missions.

Mr. Beaumont, again, referred to two-passenger vehicles and four-passenger vehicles, and so on.

With gasoline engines we're stuck. The manufacturers don't change their engine lines more often than every 8 to 10 years because of the tooling expense.

So I think this is an important thing to realize, that with electric propulsion we have the potential for an enormous variety in systems and vehicle types. It is vital that this bill let all these things be developed and tested in the marketplace.

I would just remind you of the range of vehicles that you've heard about or read about recently: The Citicar, which is Sebring-Vanguard's, is two-passenger, a little over 1,000 pounds. Another two-seater is made in Milan, Italy. It's called the Elcar and is being imported by an Indiana company. You'll be hearing about a four-seater Renault from the next speaker. Mr. Waterman's DAF also seats four. All of these cars are lighter by far than any American vehicle. The Die Mesh car that you heard of yesterday is also lighter.

Then we move all the way up to the electric fuel propulsion. Mr. Aronson, who spoke yesterday, has a full-size luxury vehicle in the Mercedes class, which I'm most impressed with. I think there's an outstanding market for it among certain individuals, who will buy and cherish it. It's an interesting development.

So here we have electric cars, going from two-seaters weighing 1,000 pounds all the way up to much larger vehicles.

I'd like to make another point which has to do more directly with the automotive industry.

We keep hearing this myth that one job in six depends upon Detroit. I swallowed that, along with most fellow citizens, until I happened to run into some research that puts this absurd claim into perspective.

The automotive industry is not first but fourth, both in terms of dollars and employment. In fact, it's way down the list in terms of number of jobs, because it's capital intensive. It ranks after health care, after food, and after construction, so we start out with that.

Further, direct employment in the automotive industry of people actually working on automobiles is 1 of every 121 workers. If we include the upstream manufacturing of glass, steel, rubber for tires, and that type of thing, it's 1 worker in 63.

Mr. Sutcliffe, whom I refer to in the written testimony, made a "worst case" situation study about what could happen in 1980, and he saw a decline in automotive employment of less than one-third of 1 percent of the then projected labor force of 100 million workers.

So I would say if we really want to get America moving let's not buy a car. Let's eat so much that we get sick and have to go to the hospital. Then we'll build more hospitals, and that's the way to get the economy moving. It's a gastronomic rather than an automotive problem.

I would make some very specific comments about the role of Detroit. I think we see clearly that they don't want to participate unless we pay them, which I think they can well afford to finance themselves.

General Motors paid $50 million for the rights to develop the Wankel engine in this country. That was straight, front-end license money, before a nickel was spent on any other form of development. That's the kind of money that General Motors pays for a new propulsion system.

I would urge that the Detroit companies not be included in the legislation we are considering here, for some of the reasons we've heard and others that we are aware of. But I think there's a much better reason, a very much better reason. There are close to 100 million American cars on the road today, and the most important thing Detroit can do is to produce more efficient gasoline vehicles while electric technology is trying to catch up. Double the mileage and reduce pollution. That should be the role of Detroit, in my estimation.

I would point out that if Detroit built all the cars contemplated in this legislation—I'm using the figure 5,000 vehicles, though I understand it may be 10,000—it would be less than two one-hundredths of 1 percent of the cars they will manufacture during the same period.

So let's not worry about Detroit getting upset because we're talking about electric vehicle procurement. That's absurd.

I mention in the written testimony the car-rail concept. In Cincinnati, today we can put a car on a flatcar and take it to Florida, while we ride in the passenger car, see a film, and have a drink. We have our personal transportation at the other end.

The same could be true of the Sebring-Vanguard Citicar, which would fit comfortably on a freight car as part of a high-speed Amtrak passenger train from Cincinnati to Columbus, Cleveland, Toledo, Chicago, or wherever. At the destination we have our electric car for local travel.

This is a very simple technology. We've already had discussions with Senator Taft's office about it.

Another concept I mention in the written testimony is what we call a "power pod," or "power pack." I had no idea Mr. Aronson had built one here until I arrived in Washington. You've perhaps seen the two-wheel trailer behind his Transformer I. That is the concept referred to on page 10 of my testimony. Basically, it's a portable generator of electricity. According to our concept, it would be rented from Hertz, Avis, U-Haul, and other such companies. If I, in Cincinnati, wish to make a trip to New York, then I would rent a "power pod," attach it to the back of my electric car, and make the trip east electrically.

This points to something else I think is very important. We've seen many references here to electric cars as a second car. Gentlemen, I believe it's our first car. It's the car we use every day for running around town, to work, to pleasure, for shopping, and so on. If we can extend the mission of our electric car by a concept such as the "power pod," we can phase our gasoline cars out. Why should I keep a gasoline-powered stationwagon for those occasional trips that are several hundred miles long? It doesn't make sense. The electric car is our first car, and I hope we can begin to conceptualize it that way.

My third comment has to do with integrated energy systems. Dr. Thornton in his testimony yesterday touched on this, and I feel it needs more emphasis. He mentioned that he is developing solar energy for his home near Concord. I think the day is not far distant by "distant" I mean a decade when we will be recharging electric vehicles from solar sources by plugging them in at home. Then we will be truly independant of foreign sources for gasoline.

I would like next to make some general comments about H.R. 6198. We've heard a lot of discussion about the cost of operation per mile. That's a "How long is a piece of string?" kind of question.

First, a philosophical observation, which is this: If we were really that concerned about the cost per mile, nobody would buy a Cadillac. People buy cars for many reasons. Performance in terms of miles per gallon is becoming an important one, but it hasn't been one for a very long time, and I think we have to look at the overall mission; we have to look at maintenance costs, which are very low in electric vehicles; and other considerations. So, we're not helping things very much by saying, "It's 5 mills more, or 10 mills less."

I'd like to give a particular example: The car that we operate currently requires close to 600-watt-hours per mile. That is a deceptive figure. The true figure should be on the order of 350-watt-hours per mile.

The reasons for this is that the transformer we use to step down from 120 volts to 48 volts is not as efficient as it should be. We tried to get a more efficient one made. It would cost us $500; money we don't have. So we put up with the situation. It's the practical thing to do. Not only could we have a better voltage match, but we could have a better method of measuring the total charge so that it would cut off automatically.

This is the kind of inefficiency that's going to be resolved, not when you have 2 vehicles or 10, but when you have 10,000 out there. We will see efficient charging systems.

So right now it's wasteful. If I gave you that figure it would be misleading. Our car should be using 350-watt-hours per mile.

Mr. Brown. Mr. Sanborn, could you try to highlight the remainder of your testimony so we may ask a few more questions, and we have one more witness?

Mr. Sanborn. Yes, sir. Specifically, then, in terms of the bill I would urge that and I use the term "subsidy," or let's call it "bounty," that's a good western term that the quickest way to get cars out is to get them out. I have grave concerns about a procurement program against a standard or specification written by someone with no experience in the industry, as Mr. Beaumont pointed out yesterday.

I prefer a form of direct subsidy—which is apparently a dirty word unless it happens to be Lockheed, or Penn Central, or somebody big enough. I think we should say to a manufacturer, "For every electric car you deliver to a customer we will write you a check for $2,000."

Now, the manufacturer has to find a customer. He has to persuade the customer to buy. He has to set up service for his customer. He has to do all these things, and if he fails, he falls flat on his face. That's the test I think we're looking toward, as to what customers really want.

Mr. Brown. I notice, just by coincidence, that the $2,000 fee you're suggesting is exactly the same amount that we wrote into the tax bill for persons who buy new homes this year.

Mr. Sanborn. I was not aware of that, sir.

So as far as participation of Federal agencies is concerned, if they want to get into the act and buy cars too, fine. But I'm very concerned about procurement by an agency for its own use. I don't know that that translates into valid experience in the marketplace.

I believe, from a comment made yesterday by Mr. McCormack, that he already has proposed accelerated rates of depreciation for purchases of electric work vehicles, such as trucks and buses. This is a wise provision.

Cincinnati has given some consideration to electric buses. We have an ideal route for them downtown, where the pollution is worst. It's a circulator route. But the city has just acquired the bus line, and it's got its hands full with other things.

If this bill, through the Urban Mass Transit Administration could make money available, I'm sure Cincinnati and other cities would be encouraged to try electric buses.

In terms of research, I would hope that an electric vehicle manufacturers council could be formed as part of this bill, along with an electric vehicle consumer council, and that the priorities for research might be determined by this council, or that they might at least have some impact on priorities for research. If we have to make some choices, let's make them on things that would advance the here-and-now technology the fastest.

I think flywheels are fascinating, but I don't think they belong under this legislation. That's a broader ERDA program, because they transcend automobiles. There are many other things, such as fuel cells and hybrid vehicles, that don't belong under this legislation. There are much more practical things—control systems, transmissions—that deserve priority.

I wanted to pick up a thing or two from the comments yesterday.

We've heard again and again a desire to focus on getting vehicles out, using the innovative companies that are in the field today as spearheads of that. I think this is very important.

I would like to make another suggestion.

The legislation makes a distinction between (1) existing chassis type vehicles and (2) new types of vehicles. I wonder if that is not really a semantic distinction. Mr. Aronson's car, for example, the Transformer I that we see parked out here, uses a body shell from General Motors. It would obviously be very foolish of him to invest in the tooling to make some other form of body shell.

What we're going to find is an á la carte approach here when we can get some kind of volume going. Particular components will be bought from particular sources, and we're going to have a transition from something that starts out as a Renault or a DAF, or whatever, but quickly becomes a true electric vehicle. The springs will be changed; the tires will be changed, and I wonder if it's useful to worry about whether the car is "existing chassis" or "new."

We should focus on getting enough electric vehicles on the road, using those that are available today. I would hope the quantity would be 20,000 rather than 5,000 or 10,000.

I have other comments, sir, but in view of the time, I'll refrain from adding those.

Mr. Brown. We welcome your comments. You've made a number of very innovative suggestions. If you would care to add in anything that isn't in your prepared statement, we would consider it as a part of your statement and include it in the full record, and you may do that at your convenience.

Mr. Sanborn. Thank you. I will, sir.

Mr. Brown. I would like, if I may, to open it up for some questions here. So if you would submit that in writing?

Mr. Sanborn. Yes, surely.

Mr. Brown. Mr. Hechler.

Mr. Hechler. In submitting your remarks in writing, any additional reactions you have to any other witnesses' before the committee would be helpful, as well as any other additional analysis of the bill.

Mr. Sanborn. Thank you, sir.

Mr. Hechler. Your testimony has been very refreshing, Mr. Sanborn. I strongly support most of the things you've advocated.

In terms of the consumer council representation, page 6 and page 10 of the bill, as I leaf through it, and also page 11, I believe, are the only mention of consumer needs. I would certainly strongly support the beefing up of the consumer representation in the form of such a council as you indicate here.

The only other question, in light of the time limitation, I have, is in your discussion of the comparison between the reactions of the auto industry in Germany and the United States in which you very graphically describe the different approaches, what's the reason why the German auto industry has taken a more progressive, imaginative view?

Mr. Sanborn. Sir, I could only speculate on that. I'm not a specialist in European affairs. I would prefer not to say things about our own industry that are——

Mr. Hechler. I think you have said things about our own industry. I think you've covered that subject, and that's the reason I directed the question.

Mr. Sanborn. All right. I have one foot in the bucket. I might as well put the other in, too.

I'm expressing, of course, a personal opinion at this point. I believe that the direction of the American automotive industry has been toward selling fantasy. The vehicles that we drive are absurd, from a transportation point of view. They weigh 4,000 to 5,000 pounds; they go from zero to oblivion in 8 seconds flat. I've seen figures that the annual value of cars manufactured is $35 billion, and the annual cost of deaths and injuries is $50 billion. $35 billion to buy 1 year's production, and $50 billion to bury and to heal those who are killed and injured.

In the testimony of the Die Mesch Corp. there was a suggestion that there be a word in the preamble about safety, and the death rate from automobiles, which tend, of course, to be speed associated and liquor associated. That's a very important consideration. Having cars moving along the road at 35 miles an hour instead of 55, I think will save lives.

I don't share General Motors' concern that the threat to safety is slow-moving vehicles. I don't think that's our problem today.

Mr. Hechler. Thank you, Mr. Sanborn.

Mr. Brown. Mr. Hayes.

Mr. Hayes. I'll defer.

Mr. Brown. Mr. Thornton.

Mr. Thornton. Mr. Chairman, if I may make just an observation, and a quick question.

I did not mean to suggest or imply in any way in the exchange a few moments ago that the DAF automobile was deficient in any manner or means. Indeed, I do not think so. It was a very fine, lightweight commuter vehicle, with limited road characteristics. I was in touch with the manufacturer at the time the decision was made not to meet the new Federal standards because of two factors. First, because it would require some expense to do so; and, second, that they had a very limited market penetration in this country at the time that decision was made.

I do not know, beyond that, the specific problems that you may be having today, but I do agree that the delay in getting an answer is inexcusable, and I think, further, that it might be well for the Congress to consider whether the same safety provisions and standards which are applicable to high-speed road vehicles are similarly applicable to the lightweight commuter type transportation vehicles, and I think this would be something that our committee might well consider in connection with this legislation.

Mr. **Brown**. Excellent suggestion, Mr. Thornton.

Mr. **Sanborn**. I would like to commend that very much, Mr. Thornton. I think that's, again, one of the institutional factors that need to be addressed, and, again, why 10,000 cars means more than 2 or 10.

Mr. **Thornton**. One other thing. When we're talking about taxes, is the Federal excise tax applicable to manufacturers of electric vehicles?

Mr. **Sanborn**. My understanding is it is; yes.

Mr. **Thornton**. That might be a possible avenue for encouraging production of electric vehicles, to make a change in that excise tax provision.

Mr. **Sanborn**. In Ohio there's a 4-percent sales tax.

Mr. **Thornton**. I have no further questions.

Mr. **Brown**. Mr. Ottinger.

Mr. **Ottinger**. Thank you, Mr. Chairman.

I just want to congratulate you for your very helpful and constructive testimony to the committee.

This car that you're using out in Ohio, is that in production now? Could somebody buy that from you?

Mr. **Sanborn**. Sir, in my written testimony I point to our frustration, that about the time we felt we had adequately tested that car it was no longer available in the States for the reason that new safety standards came into effect in 1974, having to do with bumper thickness, and the manufacturers didn't import it any more. Mr. Waterman had to start all over again with another vehicle.

So the answer is no.

Mr. **Ottinger**. He does not have a vehicle available today?

Mr. **Sanborn**. He will be selling the car shown in your brochure as soon as Mr. Dyson responds positively, as I assume he will.

Mr. **Ottinger**. Do you have any idea what the price will be on that vehicle?

Mr. **Sanborn**. It would appear to be close to $6,000, $5,800, or $5,900, so long as it is imported from Europe as a gasoline car. Now, as soon as Mr. Waterman can get into volume production—and volume means 25 or more—he can begin to fabricate in the States and bring the price down.

Mr. **Ottinger**. What is the range on that vehicle?

Mr. **Sanborn**. His experience is close to 60 miles, in part for the reasons that Mr. Thornton mentions. It has a transmission that is very efficient. Among other things, it limits torque on the motor, which, in turn, limits current flow, which means the batteries perform more efficently. It's a serendipitous sort of thing.

Mr. OTTINGER. Thank you very much, Mr. Chairman.

Mr. BROWN. Mr. Blanchard.

Mr. BLANCHARD. I hate to be put in the position of having to defend Detroit. That's an awful burden, especially when I didn't have any help from the automobile manufacturers in getting elected.

[Laughter.]

Mr. BLANCHARD. But I do have 30,000 United Auto Workers members in my district, and I have to say that I think it's in the interest of the large manufacturers to see electric vehicles succeed, because I'm quite confident they'll move in and start making them en masse, and their workers will be gainfully employed for many years to come.

I also happen to believe in the philosophy you've expressed, that it's much more likely that the small entrepreneur will be pioneering a number of new ways to move the transportation than perhaps larger institutions, just as we find Government oftentimes is the last one to react to an important problem.

I am a little intrigued with the $2,000 subsidy. It sounds good. You really aren't talking about tax credits? You're talking about a subsidy to the manufacturer who produces the vehicle.

Mr. SANBORN. To the manufacturer, yes. This is a bounty for every scalp he brings in.

Mr. BLANCHARD. I assume we're talking about requiring the vehicle to perform, not just get something in the hands of the people.

Mr. SANBORN. Yes.

Mr. BLANCHARD. Which is the last think we want to see, these people get ahold of these electric vehicles, and get their subsidies, and then find out they're not working right.

Mr. SANDBORN. I would suggest there be performance standards, and that, based on the manufacturer's literature he would be held to delivering what he promises. If he says, "40 miles," then he'd better produce 40 miles, under the conditions he specifies. I think that's essential. But it should not be a specification developed by an administrator in a government agency, who begins to add on things that are not real concerns.

Mr. BLANCHARD. That's an interesting question because, of course, there's been a lot of debate about standards, and a number of us have started to think that the best way the Government can move in the area of standards is to legislate objectives, but try to prevent either through an agency or through a bureaucrat, or through a Congress, telling someone how to meet an objective technically. Would you agree with that?

Mr. SANBORN. Yes, could I make two comments?

First: In my younger days, which dates me, our family phonograph turned at 78 rpm, and it used a steel needle, which I believe was useful for three or four plays. Now, if we were to specify that all phonographs produced under this contract must turn at 78 rpm and must use steel as a means of producing a signal, we would never have long-playing records, stereophonic sound, and all the rest. I think the performance standard is the farthest we should go. There's a great danger in people adding things on here.

We had our electric car only a matter of a month or two before we began to redesign it with this and this and this "improvement". As we ran the car longer, however, and as we discussed our ideas with the manufacturer, we found he had very good reasons for the choices he had made, all based on producing a good car at the lowest cost. Much of what we wanted to do was adding complexity and cost without a corresponding benefit.

I think one of the advantages of this legislation is that we will see a great variety of vehicles and we can test these things. Some will be very simple, very direct, like the Citicar. Others will be sophisticated, like Mr. Aronson's Transformer I.

I would like to make another comment about the industry. I think we've got to look out for the buggy whip mentality here, or the gasless carriage, I call it. We're not talking about changing propulsion alone. It's a very different thing that's coming out of this. For example, I don't see electric vehicles being produced on the enormous type of production lines we see in Detroit.

For an analogy, I think we should look at the recreational vehicle market. There are many, many manufacturers producing recreational vehicles and travel trailers. They buy components—batteries, motors, fenders, chassis, springs, et cetera—and they assemble vehicles of a particular type. This is a pattern I think we'll see in the electric vehicle industry in the future. We'll see many types of vehicles, from electric wheelchairs on up to electric buses.

Mr. BLANCHARD. I have no further questions.

Mr. BROWN. Thank you, Mr. Blanchard. Thank you very much, Mr. Sanborn. We would appreciate it very much if you would supplement your prepared testimony by submitting it writing the additional comments that you have indicated you would like to submit.

Mr. SANBORN. Thank you.

Mr. BROWN. We're grateful for your appearance here this morning.

I would like to assure the remaining witnesses we're going to run until 12:30 or so, and I hope that will give us ample time to hear them.

Our next witness is Mr. Warren Harhay, President of Electric Vehicle Associates, Inc., Brook Park, Ohio.

We apologize for keeping you as long as we have, Mr. Harhay, but we will take such time as is necessary.

Without objection, the full text of your testimony will appear at this point in the record, and you may proceed as you desire.

STATEMENT OF WARREN C. HARHAY, PRESIDENT, ELECTRIC VEHICLE ASSOCIATES, INC.

Mr. HARHAY. Thank you, Mr. Chairman and Congressmen.

[The complete prepared statement of Mr. Harhay follows:]

STATEMENT OF WARREN C. HARHAY, PRESIDENT OF EVA, INC.

THE ROLE OF SMALL BUSINESSMEN IN THE EV INDUSTRY

Mr. Chairman and gentlemen, I am Warren C. Harhay, president of EVA, Inc., Electric Vehicle Associates, Inc., a small public Ohio corporation whose goal is the design, fabrication, and distribution of electric vehicles and their support systems.

I have included in the addenda to my remarks some background information regarding myself, EVA, and our product—the EVA Electric Luxury Sedan.

Our company was an outgrowth of a vocational high school project conceived without commercial intent and executed before the energy crisis was front page news. The Project, an electric Pinto conversion was undertaken to provide a highly motivating mobile teaching aid, interdisciplinary vocational training, and to develop pride and a feeling of self worth on the part of the participating vocational students. Over 60 students in the various vocational courses participated in the project.

After being invited to display the car at the Third International Electric Vehicle Symposium held last year in Washington, D.C., I cautioned my students not to be disappointed, lest they compare our car to the well funded efforts of large corporations. I told them that we would see vehicles representing the state of the art in EV technology.

We displaced the car, and soon found out that we *were* the state of the art. Experts that we had written to months before for advice now were asking questions of us.

On the trip back to Cleveland, it struck me that here was an opportunity to become a part of this fledgling industry by providing a product of high technical integrity produced by persons of integrity.

On April 1, 1974, EVA began doing business as an Ohio corporation. Since that time, we have developed the product which was displayed here in Washington Tuesday and is described further in the Specification Sheets.

With this background in mind, I wish to address myself to the role of small business and the necessary function they can provide in the implementation of this bill.

And secondly, I respectfully submit suggestions to and modifications of H.R. 5470 in order to make it more viable and effective.

We have heard testimony regarding the relative advantages of Electrics. We have also heard some of the constraints relative to developing demonstration vehicles.

It is a fact of business life that it is easier for big government to deal with big business. Although this may make for expediency in some forms of procurement, it does not lend itself well to areas on the forefront of technology. For example, the recent EV Post Office contracts raise some very serious questions regarding procurement policies.

Small businesses are resourceful in utilizing the natural, economic and human resources of our country.

First, the small business is more cognizant of utilization to the fullest those natural resources used in tooling, fabrication, and procurement because they deal with it on a direct level.

Since the dollars invested frequently come from personal resources, the smaller entrepreneur is sure to get maximum value for each capital dollar available.

The electric vehicle components in themselves are resourceful in that all primary components are easily recyclable (batteries) or have extreme service longevity (motors, controls).

In terms of utilizing economic resources, the small business can be cost-effective in using available capital because of the lower overhead in areas of indirect labor, and organization. For example, generally engineering costs are lower because many different job roles are performed by fewer persons.

It is interesting to note that since a small business is dependent upon it's product integrity for its existence, it is sure to make every conceivable effort to advance the best product possible. If however, a large corporation with diversified incomes receives a contract to produce a novel item, it is in the enviable position of winning the war even if they lost the battle. If the novel product fails, they still can count on the sales of their conventional products.

Perhaps in so doing they lose a little face, but they are still in business. The degree of incentive for performance just doesn't exist since either way—acceptance or rejection—the large corporation's products will be purchased.

Another function of resourceful use of economic resources is the encouragement for the smaller investor in the capitalization of smaller business. Here he can again have a feeling of real participation.

Finally, America's most important national resource is its human resources. By encouraging participation of small business, new developments can be more quickly energized.

Small businesses have low inertia and can move quickly in reproducing the state of the art; thereby encouraging further development. When a man sees the fruits of his work, he is encouraged to improve upon his own developmental efforts.

In the development of this new industry, whole new areas of job skills would be created not only for production and distribution, but also for service and peripheral support. Disadvantaged persons could have varied job opportunities in the after market industries.

Since the electric vehicle is not a replacement, but a complementary alternative to internal combustion engine vehicles, job opportunities would expand.

The limited production of the vehicles would tend to encourage a more congenial working atmosphere. A reduction in tension, increase in pride of craftsmanship all contribute to job enrichment.

Companies in the electric vehicle industry now seem to have some commonality in that they demonstrate men of good will and are supportive of each other. Men that seem to have a sense of mission and of doing good for our environment, for our people and for our country.

Small businesses are resourceful in maintaining, or if you will "recharging" the weave of the American Way of preserving our heritage of self-determination, self discipline, and initiative.

Congressman, I respectfully ask you to preserve that section of the House Bill encouraging and protecting contributions by smaller businesses and individuals in the three facets (Research, Development, and Demonstration) of H.R. 5470.

I also respectfully suggest the following changes and additions for your consideration:

1. Foreign chasis based conversions should not be excluded in the conversion demonstration facet.

We would favor using American components, but as of today no American car offers the weight saving advantages found on foreign manufactured cars.

Domestic auto companies have however announced their intention to produce such vehicles.

In support of using foreign chassis, I can relate our own example of not being able to purchase a lightweight American vehicle without engine.

In our case, a European manufacturer has shown interest in providing their safety certified body and chassis without the engine for our production now underway.

2. In terms of the timing suggested in the Bill, I feel that the numbers (5000) a the time period (1 year) for conversions are at present a bit high and low respectively. I feel an extension of the time period would cause less disruption and more efficient utilization of capital and natural resources.

3. The ground up car development time is a bit short, since effective testing before introduction is essential if you truly wish to further the integration of electric vehicles into the personal transportation mode. Four to five years would be a more realistic time period.

I do not suggest a blanket safety exemption for electric vehicles. The exemption process is well defined and each situation is best handled on its individual merits. For novel products to succeed, they must not be perceived as disadvantagous in in terms of safety.

The concept of the Bill is exciting. The world community has already recognized the potential that lies in Electric Vehicle development. Hopefully, your efforts will be successful in combining American initiative and know how to become leaders in the EV world.

In total, it is an exciting bill. I appreciate your efforts on behalf of my children who probably won't have the luxury of travelling in cars fueled by liquified Dinosaurs and on behalf of the present and future members of the Electric Vehicle industry.

BIOGRAPHICAL SKETCH OF W. C. HARHAY

Warren Charles Harhay, president and founder of Electric Vehicle Associates, Inc., is a Cleveland native and a graduate of the Parma City Schools. He attended Cuyahoga Community College and Fenn Technical School. Mr. Harhay is a graduate of Cleveland State University and has done graduate work at Kent State University.

Mr. Harhay is an Advanced Class Amateur Radio operator, and holds a F.C.C. Commercial First Class Radio Telephone operator's license. He has worked during his college years at Cleveland Radio and Television Stations as both studio and transmitter engineer. He also became service manager during his college years for an electronics distributing firm.

Mr. Harhay has experience as a Field Service Engineer with Ohio Sound Systems and has been an operator of electronically automated motion picture theaters.

Immediate experience prior to founding EVA was that of Senior Electronics Instructor at Normandy High School in Parma, Ohio.

During his five years with the school, his students have reached technical distinction at state and national levels.

Mr. Harhay's interest in antique and classic automobiles spurred a class project early in 1973 that resulted in an Electric Pinto conversion.

The Pinto received national and international acclaim at the Third International Electric Vehicle Symposium held in February of 1974 in Washington, D.C.

As a result of the symposium, it became evident to Mr. Harhay that the opportunity existed for persons with technical competance and integrity to enter the fledgling electric vehicle industry.

With these factors in mind, Electric Vehicle Associates was incorporated in Ohio on April 1, 1974.

Mr. Harhay is presently a member of the Parma Jaycees, a director of the Electric Vehicle Association of Ohio, and a Red Cross Disaster Service volunteer.

He was named an "Outstanding Young Man in America" in 1972 for his service to the community.

TIRE RESERVE LOAD

This table lists the tire size designations recommended by the manufacturer for use on the vehicles to which it applies, with the recommended inflation pressure for maximum loading and the tire reserve load percentage for each of the tires listed. The tire reserve load percentage indicated is met or exceeded by each vehicle to which the table applies.

Description of vehicles to which this table applies: **EVA ELECTRIC LUXURY SEDAN**

Recommended Tire Size Designation		155 R 13	
Recommended Cold Inflation Pressure for Maximum Loaded Vehicle Weight	Front	32	
	Rear	32	
Tire Reserve Load Percentage *	Front	2	
	Rear	2	

* The difference, expressed as a percentage of tire load rating, between (a) the load rating of a tire at the vehicle manufacturer's recommended inflation pressure at the maximum loaded vehicle weight and (b) the load imposed upon the tire by the vehicle at that condition.

WARNING: Failure to maintain the recommended tire inflation pressure or to increase tire pressure as recommended when operating at maximum loaded vehicle weight, or loading the vehicle beyond the capacities specified on the tire placard affixed to the vehicle, may result in unsafe operating conditions due to premature tire failure, unfavorable handling characteristics, and excessive tire wear. The tire reserve load percentage is a measure of tire capacity, not of vehicle capacity. Loading beyond the specified vehicle capacity may result in failure of other vehicle components.

ACCELERATION AND PASSING ABILITY

This figure indicates passing times and distances that can be met or exceeded by the vehicles to which it applies, in the situations diagrammed below.

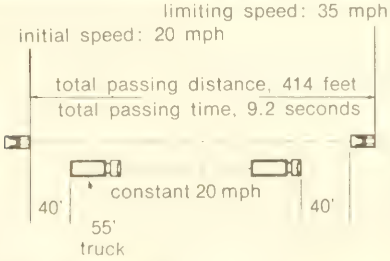
The low-speed pass assumes an initial speed of 20 mph and a limiting speed of 35 mph. The high-speed pass assumes an initial speed of 50 mph and a limiting speed of 80 mph.

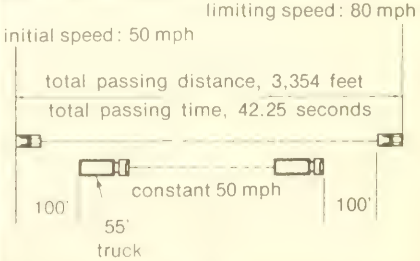
NOTICE: The information presented represents results obrainable by skilled drivers under controlled road and vehicle conditions, and the information may not be correct under other conditions.

Description of vehicles to which this table applies: **EVA ELECTRIC LUXURY SEDAN**

SUMMARY TABLE

Low-speed Passing 414 Feet, 9.2 Seconds	High-Speed Passing 3354 Feet, 42.25 Seconds

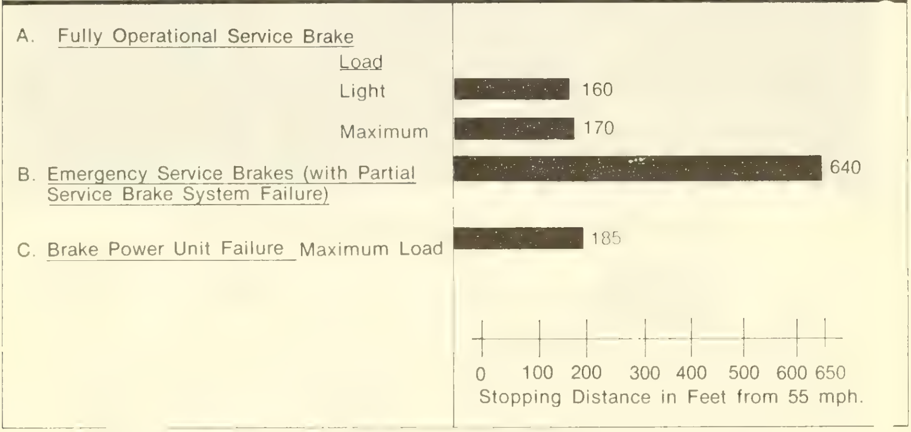




VEHICLE STOPPING DISTANCE

This figure indicates braking performance that can be met or exceeded by the vehicles to which it applies, without locking the wheels, under different conditions of loading and with partial failures of braking system. The information presented represents results obtainable by skilled drivers under controlled road and vehicle conditions, and the information may not be correct under other conditions.

Description of vehicles to which this table applies: **EVA ELECTRIC LUXURY SEDAN**



CID 575 Feb. 1975 Printed in U.S.A.

ELECTRIC ELEGANCE REBORN

EVA ELECTRIC LUXURY SEDAN

GENERAL SPECIFICATIONS

Motor: EVA 10KW series compensated traction.

Control: Smooth - efficient SCR speed control with battery and motor protection.

Battery: Electric vehicle duty, 96 volt lead/acid.

Battery Charger: On board, 110 or 220 volt with simultaneous 12 volt recharge.

Automatic Transmission (Standard): 3 speeds forward, 1 reverse, floor mounted console selector lever.

Power Brakes (Standard): Electrically provided vacuum boost power assisted dual hydraulic brake system with 9 in. diameter self adjusting disc brakes with single-piston drum brakes at rear. A pressure valve controls rear brake hydraulic pressure according to load in vehicle. Indicator light on instrument panel signals failure in front or rear hydraulic brake circuits. Cable-operated handbrake effective on rear wheels with indicator light on instrument panel: transparent brake fluid reservoir.

Steering: Rack and pinion. Turning circle diameter curb to curb. 32.8′ 3.5 turns lock to lock. Steering ratio 20:1. Maintenance free lubrication.

Suspension: Front independent with rubber-mounted pressed steel control arms with permanently adjusted and lubricated ball joints. Coil springs, double acting telescopic hydraulic shock absorbers and stabilizer bar. Rear pressed-steel live axle guided by two rubber mounted yoke-type control arm attached to center of chassis. Coil springs, double-acting telescopic hydraulic shock absorbers with travel limiters incorporated.

Tires: 155R13 whitewall steel/belted radial tires on custom slotted 4.50 rims.

Dimensions: Wheelbase 96″. Overall length: 174″. Height (empty) Sedan 56.6″. Width: 64.5. Ground clearance (loaded) 5.5″. Weight 3150 lbs. (approximately).

Heating & Ventilation: Heavy-duty heater and defroster with variable temperature control 2-speed heater blower. Flow-through ventilation system.

Special Features (Standard):

Foam-filled front reclining bucket seats with vinyl upholstery and built-in head-rests. Full width raised edge parcel shelf under dash. Front hinged engine compartment lid with inside release. Unitized construction with factory applied undercoating and rust-proofing. 2-speed wide-arc electric windshield wipers, adjustable dual jet electric windshield washers. Energy absorbing front/rear bumpers with side mounted rubber pads. Side lights and reflectors, front and rear. Front lap-shoulder belts with inertia reel and starter interlock; rear lap belts with automatic-lock retractors. Roll-down rear windows. Outside rear view mirrors. Laminated, impact-absorbing safety glass all-around. Back-up lights. Emergency 4-way flashers. Ignition switch/steering wheel lock. Ignition key/door-ajar reminder light. Padded dash, padded steering wheel, padded door panels, padded headlining and padded sunvisors. Impact-absorbing steering column. Inside day/night rear view mirror with break-away base. Trip odometer. Spare wheel cover. Protective chrome side mouldings and luggage compartment chrome trim. Cigarette lighter. Dual horns. Rear window defogger. Power-assisted dual brake system. Deluxe radio console. Tinted glass. Contour rear bench seat with fold-away armrest. Glove compartment light.

EVA . . . THE ELEGANT ALTERNATIVE

ELECTRIC VEHICLE ASSOCIATES INC.
P. O. Box 9803
Brook Park, Ohio 44142

EVA

ELECTRIC VEHICLE ASSOCIATES INCORPORATED

COSTS OF OPERATION

FUEL

ELECTRICITY TO TRAVEL ONE MILE= 0.38 KWH	1.3 cents

PROPULSION SYSTEM CONSUMABLES

BATTERY AMORTIZATION @ 27,000 MILES $540.	2.0 cents
DISTILLED WATER 500 MILES/GALLON 50¢/GAL	0.1 cents
MOTOR BRUSH REPLACEMENT $ 18.@ 18,000 MILES	0.1 cents
TOTAL FUEL AND PROPULSION SYSTEM COSTS/ MILE	3.5 cents

ECOLOGICAL COSTS

EMISSIONS	1975 EPA MOTOR VEHICLE STANDARD	EVA ELECTRIC*
HYDROCARBONS	1.5 gram per mile	less than .04gm
CARBON MONOXIDE	15.0 gram per mile	negligible
OXIDES OF NITROGEN	3.1 gram per mile	1.4 gm/mile

* THE EVA ELECTRIC IS BY ITSELF INHERENTLY NON-POLLUTING, HOWEVER. THESE FIGURES TAKE INTO ACCOUNT THE POLLUTION RESULTING IN THE GENERATION OF ELECTRICITY TO RECHARGE THE BATTERY PACK. FIGURES ARE DERIVED FROM 1975 EPA STANDARDS FOR POWER PLANTS USING COAL AS THE FUEL SOURCE.

EVA Electric Luxury Sedan

Advanced engineering takes a back seat only to the luxury appointments of the EVA Electric Luxury Sedan. Standard features include automatic transmission, power disc brakes, tinted windows, whitewall radial steel/belted tires, and a smooth-riding suspension. Reclining bucket seats, rear seat folding arm rest, rear window defoggers, slotted spoke wheels accent the advanced Electric Propulsion System.

General Specifications EVA Electric Luxury Sedan

MOTOR EVA 10KW series compensated traction

BATTERY Electric vehicle duty, 96 volt lead acid

CONTROL Smooth, efficient SCR speed control with battery and motor protection

BATTERY CHARGER On board, 110 or 220 volt with simultaneous 12 volt recharge

AUTOMATIC TRANSMISSION (Standard): Electronically governed, electrically shifted, 3 speeds forward, 1 reverse, floor mounted console selector lever.

POWER BRAKES (Standard): Electrically provided vacuum power assisted dual hydraulic brake system with 9 in. diameter self-adjusting front disc brakes with single piston drum brakes at rear. A pressure valve controls rear brake hydraulic pressure according to load in vehicle and [illegible] light in instrument panel signals failure in front or rear hydraulic brake circuits. Cable operated handbrake effective on rear wheels with indicator light in instrument panel, transparent brake fluid reservoir.

STEERING: Rack and pinion. Turning circle diameter curb to curb 32.8', 3.5 turns lock to lock. Steering ratio 20:1. Maintenance free lubrication.

SUSPENSION Front independent with rubber mounted pressed steel control arms with permanently adjusted and lubricated ball joints. Coil springs, double acting telescopic hydraulic shock absorbers and stabilizer bar. Rear pressed steel live axle guided by two rubber mounted yoke type control arm attached to center of chassis. Coil springs, double acting telescopic hydraulic shock absorbers with travel limiters incorporated.

TIRES 155R13 whitewall steel belted radial tires on custom slotted 4.5J rims

DIMENSIONS Wheelbase 96. Overall length 174. Height, empty, Sedan 56.6. Width 64.5. Ground clearance, loaded 5.5. Weight 3150 lbs (approximately)

HEATING & VENTILATION Heavy duty propane heater and defroster with variable temperature control 2-speed heater blower. Flow through ventilation system.

SPECIAL FEATURES (Standard): Foam-filled front reclining bucket seats with vinyl upholstery and built-in head-rests. Full width raised edge parcel shelf under dash. Front hinged engine compartment lid with inside release. Unitized construction with factory applied undercoating and rust-proofing. 2-speed wide-arc electric windshield wipers, adjustable dual jet electric windshield washers. Energy absorbing front/rear bumpers with side mounted rubber pads. Side lights and reflectors front and rear. Front lap-shoulder belts with inertia reel and starter interlock, rear lap belts with automatic-lock retractors. Roll-down rear windows. Outside rear view mirrors. Laminated, impact-absorbing safety glass all-around. Back up lights. Emergency 4-way flashers. Ignition switch steering wheel lock. Ignition key/door ajar reminder light. Padded dash, padded steering wheel, padded door panels, padded headlining and padded sun-visors. Impact-absorbing steering column. Inside day/night rear view mirror with break-away base. Trip odometer. Spare wheel cover. Protective chrome side mouldings and luggage compartment trim. Cigarette lighter. Dual horns. Rear window defogger. Power assisted dual brake system. Deluxe radio console. Tinted glass. Contour rear bench seat with fold-away armrest. Glove compartment light.

ELECTRIC ELEGANCE REBORN

Mr. HARHAY. I, first of all, would like to thank the committee, and I think it's a testimonial to our form of government that not only did we hear the voice of the largest automobile manufacturer in the United States and in the world, but we're also going to hear the voice of perhaps the smallest.

I would also like to assure Mr. Blanchard that when he's speaking with me he's also speaking with not only the chairman of the board but also an assembly lineworker.

Electric Vehicle Associates was formed and conceived from a high school project. It began about 3 years ago. We found that there were two things that captured the imagination and interest of teenage boys: cars and girls. There's not too much we could do about girls, but by integrating the automotive interest of high school youth, along with the technology involved with electric controls, electric motors, we were able to develop a project where we converted an electric Pinto.

We finished the Pinto. The project had no commercial intent. We had no plans of production. We were very naive in what we were doing. But we finished the Pinto in the middle of the oil embargo. We received a lot of notoriety, and as a result, at the completion, or fruition, of our project, we were invited to take the car to the electric vehicle symposium held in Washington, D.C., last February. I cautioned my students, lest they be disappointed, that the fruits of our efforts compared against large corporations, who had lots of money to invest in prototype vehicles. I told them that we would be seeing a state-of- the-art. It was to my surprise that when we arrived we found out that we were at the state-of-the-art, and that some of the people that we had asked questions of and asked for advice over the last 3 years now were asking us, "How did you do it?"

On the return trip back to Cleveland, it appeared to me that it would seem to be an opportune time, that there was still room in America for a person with initiative to form a company and go into business, and so, with some other interested parties in Ohio, we formed EVA, Inc., last April 1. There's some amount of humor regarding April 1, April Fools Day, but we feel that we'll fool everybody with our attempt.

Mr. HECHLER. Usually EVA to our committee means extra vehicular activities.

Mr. HARHAY. We picked the name because it has space connotations, and we like to feel that we are on the forefront of technology, so it was no mistake that we used EVA as an acronym for our name.

With this background in mind, I would like to address myself to the questions and the issues that face the small businessmen, almost now the microbusinessmen in the electric vehicle industry; and also, I would like to submit respectfully some suggestions and modifications to the proposed bill.

We've heard testimony this last week relative to the advantages of electric vehicles, and then of some constraints regarding the development of electric vehicles.

It's a fact of business life, as you all know, that it's easier for big government to deal with big business. This might make for expediency in matters of procurement, but it does not lend itself well, I believe, to areas that are on the forefront of technology. For example, the recent Post Office EV contract raises questions regarding these procurement policies, as alluded to in previous testimony.

Smaller businesses can and do offer definite advantages. Smaller businesses are resourceful in utilizing the natural, economic, and human resources of our country.

First, the small business is cognizant of the utilization to the fullest of those natural resources used in tooling, fabrication, and procurement because they deal with it on a more direct level.

Since the dollars invested frequently come from personal resources, the smaller entrepreneur is sure to get maximum value for each capital dollar available.

The electric vehicle components regarding the cars are in themselves more resourceful, in that batteries are recyclable, and the motors and controls have extreme longevity.

Second, in terms of using economic resources, the small business can be cost-effective in using available capital because of the lower overhead in terms of indirect labor. For example, engineering costs. You'll find the engineer is frequently the manager. In our case he also is the floor sweeper, along with a number of other engineers, vice presidents in our corporation. They all share the broom.

It's interesting to note that since a small business is dependent upon product integrity for its existence, it will make every conceivable effort to provide the best product possible.

If, however, a large corporation, with a diversified income, receives a contract to produce a novel item, it is in the envirable position of winning the war even though it might lose the battle. If the novel product fails, they can still count on the sales of their conventional products. Perhaps they might lose some face, but they can still exist, and so there still is not that degree of incentive that exists for the smaller manufacturer. The large corporation's products will be purchased either way, conventional or the novel product.

Another function of resourceful use of economic resources is the encouragement of the smaller investor in providing the necessary capitalization of smaller businesses. Here the smaller investor can give a feeling of real participation by his contribution.

I might add that the Government recognition of the industry would not only have the $40 million per year proposed, but also stir up interest in the private financial world for the people who are presently in the industry, and those who will enter it in the future.

Finally, America's most important national resource is its human resources. By encouraging participation of small business, new developments can be quickly energized.

Small businesses have low inertia and can move quickly in reproducing the state-of-the-art; thereby encouraging further development. When a man sees the fruits of his work, he is encouraged to improve upon his own developmental efforts.

In the development of this new industry, whole new areas of job skills would be created, not only for production and distribution, but also for service and peripheral support. Disadvantaged persons could have varied job opportunities in the after-market industries, as well as in the initial production. This is a big concern today, about training disadvantaged persons. If you have to retrain them, you might as well retrain them for the new jobs that are going to be existing.

Since the electric vehicle is not a replacement, but a complementary alternative to the internal combustion engine vehicle, job opportunities would expand rather than contract.

The limited production of electric vehicles would tend to create a more congenial working atmosphere by reducing tension and increasing pride of craftsmanship, and thereby contribute to job enrichment.

Companies in the electric vehicle industry now seem to have some commonality in that they demonstrate good will and are supportive of each other. They comprise men, as you've probably seen, who seem to have a sense of mission about them, and of doing good for our environment, for our people, and for our country.

Small businesses can be resourceful in maintaining, or if you will, recharging the weave of the American way by preserving our heritage of self-determination, self-discipline, and private initiative.

Congressmen, I respectfully ask that you preserve and strengthen that section of House Bill 5470 encouraging and protecting contributions by smaller businesses and individuals in each of the areas of research, development, and demonstration.

I also respectfully suggest the following changes and additions for your consideration:

One: Foreign chassis based conversions should not be excluded in the conversion demonstration facet.

We would favor using all American components, but as of today no American manufacturer provides the weight saving advantages found on foreign manufactured vehicles.

Domestic auto companies have, however, announced their intention to produce these cars in the future. How far in the future is not definite right now.

In support of using the foreign chassis, we can relate our own example of not being able to purchase an American lightweight vehicle without the engine.

In our case, a European manufacturer has shown interest in providing their safety certified body and chassis without the engine for our production, which is now underway.

In terms of the timing suggested in the bill, with the present state of the industry, I feel that the numbers 5,000 and the time period of 1 year for the conversions are a bit high and low respectively. I think this has been addressed, and may be that's a minor point. That could be stretched out.

The ground up car-development time, I feel, also is a bit short for that same amount of numbers, and the reason here is not that I wish to delay in any way the implementation of the bill, but I feel it's very important that new and novel products should be fairly well tested, first of all, before someone gets killed in an electric car and dooms the whole industry to failure right from the beginning. I do not favor a blanket safety exemption, therefore, for electric vehicles.

In hearing the previous testimony, however, I would encourage expediency in granting the exemptions that are provided for under law for low emission vehicles, and using existing legislation already in effect to its fullest extent would probably be the most expedient way.

At this point I would like to insert just a few comments, personal comments, regarding the testimony of the representatives from General Motors. However, I don't know how much weight my voice will hold. I would just like to add some personal testimony regarding these constraints that were listed on page 16 of the testimony of General Motors.

They believe that a significant number of electric vehicles—first of all, "significant," when you're talking about 5,000 vehicles to GM you're talking about 15 minutes production, and I don't believe that "significant" relates to GM in that particular manner.

Also, they use the word "costly." Well, $120 million, or $40 million per year, viewed in the perspective of other programs, other research projects, is not costly.

The other thing, when he says "real benefit" here, the real benefit is, gentlemen, you would be stimulating a whole new industry, and a whole pile of new jobs in job training.

Also, "uninformative regarding batteries," I don't believe this is true. Basically, it's a chicken and egg situation right now: Which comes first? We don't have the batteries, so we don't make the cars, or we don't have the cars, so we won't make the battery. There's no market for the cars, so we won't make the battery.

Well, we have to start someplace. This is what we thought last year, and this is why we started.

"Mix a low performance vehicle population with the high performance vehicles." I can assure you gentlemen that very few people would drive the Citicar on an Interstate System going only 30 miles an hour. They know they can't do it.

In Cleveland we have a group, a club, of people owning about 25 electric vehicles. In the 4 or 5 years that these vehicles, built by private individuals, have been in operation there hasn't been a single accident involving them. They've been well integrated. They can meet the standards, and the people who are driving them know the limitations of the vehicles, and they won't attempt to try to pass a truck going 50 miles an hour when they know it will take a minute and a half to pass the truck. They know what the limitations are.

In terms of power utilization, all I can say is my personal testimony, using electric cars for 2½ years, paying $50 a month for one car for gasoline, and it cost me approximately $5 in 4 months additional on my electric bill to drive the electric with the same or comparable duty and distance.

Incidentally, it doesn't cost anything to plug your car in at work, in terms of cost to a person.

Now, in conclusion, I think that the concept of the bill is well conceived. The world community has, as previously testified, already recognized the potential of electric vehicles. Hopefully, your efforts will culminate in America becoming world leaders in the electric vehicle development, as a result of American initiative and American know-how.

I appreciate your efforts on behalf of my children and their children, who won't have the luxury of traveling in cars fueled by liquified dinosaurs, on behalf of the present and future members of this industry, and on behalf of our Nation.

Mr. Brown. Thank you very much, Mr. Harhay, for your testimony. I note that you are a member of the junior chamber of commerce, and have been honored by that fine group of young men, and I can say that your activities are a tribute to them, and we hope that you will continue with the innovative type of work that you are doing.

Mr. Winn, do you have any questions?

Mr. **Winn.** I have no questions, Mr. Chairman. Thank you.

Mr. **Brown.** Thank you.

Mr. Hechler.

Mr. **Hechler.** Thank you. I congratulate you too, Mr. Harhay, for being named "Outstanding Young Man in America."

I notice that you distributed the Consumer Information Data Book.

Do you have any reactions to the testimony of the previous witness, Mr. Sanborn, about an additional consumer council in the legislation that would formally give status to consumer representation?

Mr. **Harhay.** I think that would be a very valid point.

In designing our car, what we tried to do was make it consumer oriented, to have it have the kind of features that you give the person, give his wife the key, and she could drive the car without any new knowledge, and I think this kind of input would be very helpful to the industry.

Mr. **Hechler.** I'm very impressed by the work that you've done with students, and it seems to me that they could well constitute a cutting edge here towards stimulating additional interest in public acceptance.

Are you still carrying on this type of work, in light of your current responsibility?

Mr. **Harhay.** The electric Pinto was last year's project. So this year's class was extremely upset when we didn't have another car to convert, and so they're presently converting a motorcycle to electric propulsion as a project. However, we don't anticipate next year going into production with an electric motorcycle.

Mr. **Hechler.** Aside from your personal involvement, it seems to me that if this could be spread across the Nation we'd be a lot further along. Don't you think so?

Mr. **Harhay.** I think so. We have received a number of different inquiries, as a result of some publication in Popular Science Magazine describing our work as state-of-the-art. We've received much inquiry throughout the Nation from other vocational schools, other universities, on how we did it, and we've cooperated with them in showing what we've done, and helped them along, so they don't have the same kinds of difficulties we had in our developmental work.

Mr. **Hechler.** Thank you, Mr. Chairman.

Mr. **Brown.** Mr. Hayes.

Mr. **Hayes.** No thank you, Mr. Chairman.

Mr. **Brown.** Mr. Thornton.

Mr. **Thornton.** Mr. Chairman, I have no questions, but I do want to congratulate you for the imaginative work you've done, and for your testimony today. It's very nice to have you with us.

Mr. **Harhay.** Thank you.

Mr. **Brown.** Thank you very much, Mr. Harhay. I do feel that your contribution has been exceptional, and we appreciate it very much.

Our last witness this morning is Mr. Harry Yoder, president of the Battronic Truck Corp.

You also had a vehicle here on display if I recall correctly.

Mr. **Yoder.** Yes.

Mr. **Brown.** We're very happy to have you here this morning, and you are our windup witness, so give it everything you've got.

STATEMENT OF HARRY D. YODER, PRESIDENT, BATTRONIC TRUCK CORP.; ACCOMPANIED BY ARTHUR DICKER, JR., CHIEF ENGINEER, BATTRONIC TRUCK CORP.

Mr. YODER. Mr. Chairman and members of the Subcommittee on Energy Research, Development, and Demonstration: I'm accompanied by Mr. Arthur Dicker, Jr. He's the chief engineer for our company, and he's with me here.

Mr. BROWN. We welcome you here also, Mr. Dicker. Your full statement, Mr. Yoder, will be inserted in the record, and you may proceed in whichever way you wish.

I would also like to have the biographical sketch, which is a part of your statement, included in the record.

[The prepared statement of Mr. Yoder, together with biographical data, follows:]

HARRY D. YODER

Harry D. Yoder resides at 200 Orchard Hills Drive, Boyertown, Pa. 19512. He is a graduate of the University of Maryland (B.S.).

Mr. Yoder was a career officer, with an Aeronautical Rating of Command Pilot, United States Air Force for thirty years. He retired from the United States Air Force in 1969 with the Rank of full Colonel. While in the Air Force he was a Group Commander. His Staff assignments included Major Command, Air Staff, the Joint Chiefs of Staff. Upon termination of his career with the United States Air Force he accepted a position with Lockheed Aircraft Corporation in their Marketing Department. He published, "Logistics in Motion" which contains detail concepts for removal of heavy logistic support at overseas military locations performing this support at depots in the United States. This concept envisions the support of the use of C-5 Airlift. His speaking experiences include lectures to students in air logistics at the Air Force Institute of Technology at Wright-Patterson Air Force Base, Texas A. & M. on Air Transportation in the Future, presentations on electric battery-powered vehicles to the Council on Environmental Quality, Advisory Committee on Advanced Automotive Power Systems and the Environmental Protective Agency.

Currently Mr. Yoder is president, of Battronic Truck Corp., Third and Walnut Streets, Boyertown, Pa. 19512.

Mr. YODER. The Battronic Truck Corp. appreciates the opportunity of presenting our views to encourage the support of electric battery-powered vehicles, and specifically H.R. 5470.

In my presentation I will be discussing: The background of our company. Our company achievements under the research and development program with regard to electric vehicles. The company experience with vehicle manufacturing. What can the electric vehicle achieve? I'll have some recommendations with regard to Federal Government assistance to the electric vehicle industry, and our conclusions.

First, the background of our company: The Battronic Truck Corp., is a wholly owned subsidiary of the Boyertown Auto Body Works. The Boyertown Auto Body Works, located in Boyertown, Pa., was organized December 3, 1972, and we manufacture electric vehicles, and gas and diesel vehicles as well, and bodies on all types of vehicles. The Battronic Truck Corp., started the manufacture of electric vehicles as a joint venture in 1962. This joint venture consisted of Smith Vehicle of England and Electric Storage Battery in Philadelphia, Pa., and our company. Each company contributed their expertise to produce the best electric vehicle that the state-of-the-art permitted.

The joint venture continued until 1966. At that time Smith Vehicle of England discontinued their operation in order to apply their resources to the electric vehicle industry in England, and I believe today there are approximately 45,000 electric vehicles operating in England alone.

The Electric Storage Battery and our company continued until 1969, when Electric Storage Battery requested that our company take over the sole ownership of Battronic Truck Corp. Battronic Truck Corp., was reorganized in 1969, and we continued to apply our own resources to the development and manufacture of electric battery-powered vehicles. We started to work very closely with the engineers of General Electric and the major battery companies to improve the propulsion of electric vehicles.

Next, the company achievements under our research and development program: We channeled all of our capabilities into walk-in vans and buses consisting of the 4,000 and 16,000 pound gross vehicle weight category. We do not manufacture passenger automobiles, and do not intend to do so in the future. By having our engineers work with the General Electric engineers, we matched the controller to the motor and the battery system to provide a reliable and efficient propulsion system. This propulsion system is designed for the urban service vehicles we are manufacturing.

Our motor/controller system has been progressively improved from 72 volt, 84 volt, 96 volt, and currently we are using 112-volt propulsion system to meet the speed and range requirements of our customers. We have improved the performance of the electric vehicle by a factor of two in the past year or so.

Our vehicle was traveling at approximately 25 miles an hour before this improvement, and today, of course, there's a much greater improvement. This was achieved as a result of a contract we received from the Electric Vehicle Council for the manufacture of 107 electric battery-powered Minivans for the utility industry in the United States and Canada.

This vehicle is equipped with the latest GE motor/controller and lead-acid battery to provide a high energy source. This vehicle is capable of achieving better than the highway speed of 55 miles an hour. At this speed the vehicle is capable of achieving approximately 25 to 30 miles on a battery charge. At 20 miles per hour the vehicle is capable of achieving approximately 68 miles on a battery charge. It uses approximately 1 to 1.5 kilowatthours per mile, depending on the speed. It can accelerate from 0 to 30 miles per hour in 9.1 seconds. Incidentally, our vehicles were tested by the Dana Corp., at Ottawa Lake, Mich., independent testing laboratory, to confirm the performance statistics I have quoted to you.

We developed and patented our quick-change battery system. This patent number is 3708028, dated January 1973, and is under the name of Paul R. Hafer, chairman of the board and chief executive officer of our company.

This system is designed to permit operating the vehicle around the clock. A discharged battery can be changed, and a newly charged battery inserted into the vehicle in less than 5 minutes. It has been our policy to manufacture the battery case, and the battery company fits the cells to the case to conform to our specifications. This procedure allows us to utilize the quick-change battery system and tailor the battery requirements to the customer's need.

Next, company experience with vehicle manufacturing: We believe our company is the first one to start mass production of electric vehicles, since the manufacture of electric vehicles has been dormant for the past 50 years or so. The vehicles we produced were of the minivan type capable of carrying approximately 1,000 pound payload. The vehicles we manufacture are standard sizes—they are not miniaturized. Each vehicle we produce meets the Federal Motor Vehicle Safety Standard.

Some of the major problems we have encountered in manufacturing are obtaining, in a timely manner, the proper components from the automotive industry peculiar to electric vehicle propulsion. Lead time for motors, controllers, and axles was approximately 9 months. The cost of the components is extremely high because of the low volume used in manufacturing, up to this period of time. At the present time we are manufacturing the following vehicles: Minivan, with 6- and 8-foot bodies mounted on this particular chassis; merchandiser vans—these are 10- and 12-foot bodies, and they're 78 inches wide; merchantvans—we have three models with 12, 14-, and 15-foot bodies, 90 inches wide; we have three buses—12-, 16-, and 22-passenger buses; and a jitney bus—18 to 20 passenger, and one of these vehicles is used in the western part of Pennsylvania by the Mushroom Farm to transport personnel from the mine to the administrative facility.

Our company has the capability of manufacturing 20 to 30 vehicles per day. We have facilities in being, and a trained work force capable of producing high quality vehicles.

Next: What can the electric vehicle achieve: It is our philosophy that the urban service vehicle is ideally suited for electric propulsion because of its planned route structure on which it operates. This type vehicle is controlled on its routes. It is more or less captive on its routes. It does not operate at random, and most often travels at speeds and distances that are well within the capabilities of the lead-acid battery.

We have a vehicle operating in New York City. It is on the route 6 hours and 15 minutes. It travels 17½ miles. It covers that 17½ miles in 1 hour and 15 minutes. Before a diesel-powered vehicle was used on this route, and, of course, there was considerable engine idling time. The only time that energy is used in the electric vehicle is when it is moving or when propelled, and not while coasting or stopped. The driver in the cab of the van in the summer months will ride at least 20° cooler, making it more comfortable for the driver, less noise, less fatigue, and, of course, no emissions.

The urban service type electric vehicle, which we are currently manufacturing, can save energy, assist in reducing harmful emissions and noise factors. The batteries can be charged during off-peak hours and the energy can be stored in them for future use. By using this off-peak energy, additional revenues would be provided to the utility industry. Accordingly, the overall electricity cost should be reduced to a lower level for the consumer. Much of this off-peak energy is not used at the present time. Potentials for cost and energy savings are substantial. The electric vehicle can make contributions to combat inflation, conserve fossil fuel by the more efficient use of available electric energy. It can be used with substantial increase in nonpolluting efficiency in the urban service fleet in meeting transportation requirements for fleet operators who depend on the present wholesale and retail distribution systems. Most every item consumed in the United States is, at one time or another, delivered by an urban service vehicle.

Frequently, the question arises as to whether the savings are real or whether the energy is transferred from the gas tank to the electric utility generating plant. It has been easy for that idea to be publicized because people frequently picture tall smokestacks belching forth contaminates which supposedly means wasteful and lost energy. Actually, this does not happen at modern efficient generating plants. For example, in 1925 it took approximately 25,000 Btu's to generate 1 kilowatt of energy. Today it takes approximately 9,000 Btu's to generate 1 kilowatt of energy. Nuclear and hydro energy will fuel most of the new and converted power generated systems from oil and gas now used in 74 percent of generating plants. By the year 2000 this will reduce to 58 percent, so that the cost of diminishing supply of oil and gas will cause scarcities that will only increase the cost of gasoline and diesel fuel, whereas better utilization of fuel will resist cost increases of these types of fuel for electric energy. Conservative calculations indicate that it takes about 2½ times more crude oil to power a gas engine than to generate 1 kilowatthour needed to power the electric vehicle the same distance. When this is translated into urban service type operation, the ratio of idling time of continuously running internal combustion engine compared with intermittent energy use of electric drive system, the ratio becomes a 6-to-1 efficiency advantage of the electric vehicle over the vehicle powered by the internal combustion engine. The urban service vehicle is inefficient and a high consumer of fossil fuel. This is because of the idling time. In many of the studies we found that some of the vehicles idle up to 70 percent of their time. Moreover, this type of vehicle is most difficult to clean up to meet ecology standards. Efforts to promote the urban service electric vehicle should receive high priority. It is ideally suited to satisfy requirements in an efficient manner.

Next; steps which the Federal Government can take to provide assistance to the electric vehicle industry: The U.S. Government is one of the largest users of urban service type vehicles. It would be highly desirable for the U.S. Government agencies to employ fleets of electric vehicles. We believe that fleets of vehicles will be successful, rather than employing one or two vehicles. These fleets of vehicles should be adequately supported logistically, by properly trained personnel, in order to assure a reasonable degree of success. Our experience has shown if one or two vehicles are employed they are not supported properly from the logistic point of view. Some of the large fleet vehicle users which we see are the Department of Defense, operating most of their vehicles on military installations in a confined area tightly controlled; the U.S. Postal Service operating vehicles on park and loop type requirements; the Department of Interior; National Park Service operating vehicles in the confines of the Park Service; and the Federal Energy Association. These Government agencies should be contacted to employ fleets of vehicles of at last 10 to 20 vehicles with proper logistic support at various locations throughout the United States. The Federal Energy Association, in collaboration with industry, could draw up plans for the types of vehicles required, together with the necessary logistic support.

We believe that Federal funds should be provided for the following: Development of high energy batteries. Development of peculiar componentry for electric vehicles, such as axles, motors, controllers, fuel gage, DC to DC converters.

We believe that the electric vehicles should be employed as a system and that provisions be made to support it as a system.

Development of support which can possibly be obtained through the oil companies who currently sell fuel for the internal combustion engine through their network of service stations located throughout the United States. I believe this is the same system that Germany is working on at the present time, and Dr. Müller from Germany has visited us several times. I believe they are working on a similar system for their autobahn road network where the service stations charge the batteries, and the driver stops at the service station to procure a battery recharged. This apparently has worked out to be a statisfactory system.

We concur that H.R. 5470 should give preference to small businesses, especially companies who have been doing research and development work using their own funds to defray expenses.

Development of technical training programs for drivers and technical personnel. We believe that comprehensive training courses should be established to familiarize personnel with the peculiarities of electric vehicle propulsion. Moreover, this training should apply to both drivers and technical personnel.

We recommend that section 4061 of the Internal Revenue Code of 1954 specifying the 10-percent Federal Excise Tax applying to vehicles with a gross weight of 10,000 pounds or more should be repealed as pertains to electric battery-powered vehicles.

We recommend a 25-percent investment credit be established for the procurement of electric battery-powered vehicles. We note that chapter 15 of the Internal Revenue Code allows a 7-percent credit for trucks if they can be applied to a business or trade. We would recommend the 7 percent be increased to 25 percent as an incentive to purchase and utilize electric vehicles.

In conclusion, we believe that H.R. 5470 will be the initial step required to get the industry started in the United States. Industries in foreign nations have been receiving financial assistance for several years to improve the state-of-the-art electric vehicles.

I have recently spoken with Prof. Gene Smith at the University of Michigan. He was on a sabbatical in Japan, and he indicated that $14 million has been allocated to the industry in Japan since 1971 for the development of electric vehicles.

These Japanese companies have already started to invade the United States with their products. Our company has vehicles in being today that can be applied and used to conserve energy, reduce cost, and assist in eliminating pollution and noise in our large cities.

We feel the urban service vehicles are ideally suited for electric propulsion because of their planned route systems on which they operate.

We invite you to drive our vehicle, observe its outstanding performance characteristics.

Our company is prepared to provide any additional information you may require with regard to the manufacture and performance of our electric vehicles.

Thank you very much, sir.

Mr. BROWN. Thank you very much, Mr. Yoder. Your testimony because of the experience that your own company has had, is extremely helpful to us on the committee.

Could you offer an estimate as to how quickly you could expand your production to meet the increased market for electric vehicles, in case such a market should be created as a result of legislation of this sort? Could you give us an idea of the number of vehicles you might be able to produce. given the market for it, without extensive capital investment, for example?

Mr. YODER. I would say if we could get our components from our suppliers, our automotive suppliers, our work force, and our tooling, our manufacturing, our machinery is in being, I would say within 6 months we could be manufacturing 10 to 15 vehicles a day, and expand that number in another 3 months to possibly 30 vehicles a day.

Mr. BROWN. I see. Mr. Thornton, do you have any questions?

Mr. THORTON. Thank you, Mr. Chairman. I would like to commend the witness on his good testimony.

The type vehicle which you are manufacturing is, it seems to me, one which is more clearly ready now for use for the purposes for which it was designed.

Mr. YODER. Yes, sir.

Mr. THORNTON. And I think emphasis should be given to this type of equipment.

I would like to ask whether you've given thought to the possibility of modifying the equipment toward a hybrid-type vehicle, for stretching out its capacity, or do you intend to keep it all-electric with the battery change capability taking care of the problem of extending range?

Mr. YODER. Yes, sir, we have given some thought to the hybrid vehicle. We have looked into it. We have not done any work in the hybrid field at all. We have concentrated all our efforts into the quick-change battery arrangement, while one battery is being used the other is being charged, and this is what we are working on primarily.

I do not think at this point in time we have found a specific powerplant that we could use to generate the energy for the batteries. We're hoping possibly that we would get a better battery with a high energy source, that we could get away from the hybrid completely.

Mr. THORNTON. I do have a very slight concern about the comparisons on fuel efficiency which you used. I personally am persuaded by some of the other evidence that the committee has received that when you are comparing vehicles of similar performance capabilities, and not comparing vehicles of dissimilar performance capabilities, that the overall energy conversion factor is approximately equal, whether the oil is consumed in the generator plant with the loss attendant upon production and transmission of energy, and going into the electric vehicle, and the further losses there, with those experienced by an internal combustion engine also consuming oil and gas.

You state the efficiencies are greater, and I wonder if you are not comparing your vehicle with vehicles which might not be by comparison overpowered.

Mr. YODER. This is possibly true. Some of these vehicles are overpowered. We agree with this, and we do notice many of the vehicles that we are getting now, put bodies on, that we are receiving six-cylinder engine vehicles more than the eight-cylinder engine vehicles.

I am going to let Mr. Dicker address this because he is familiar with this.

Mr. DICKER. I was going to ask the question: Why are they overpowered?

Mr. THORNTON. I think that we have been reaching at that point for some time. It seems to me that there has been maybe an undue emphasis placed upon certain performance characteristics, which are not really useful in the type of transportation which is now needed.

I think the changes should be made. Do not misunderstand my question as being antagonistic toward the electric vehicle. The question is intended to insure that there be no mistake about the relative efficiency when compared with another vehicle of similar size.

Mr. YODER. I think also, with the multistop vehicle, or the urban service type vehicle, one of the things we find, Mr. Thornton, is the fact that these vehicles idle so extremely long when they are doing their work, and this is where they develop a lot of maintenance problems. The engines do not meet the emissions requirements. I think the standard is 10-percent idling, and we are finding that in many of the surveys we are making they idle 50 to 70 percent, while the vehicle is operating, stopping for traffic, or stopping for a traffic light, making deliveries, or what-have-you, while it is on the route. Many of the operators, or many of the users, that we are making surveys for are utterly amazed at the number of stops and starts that our surveys find, and also the distance that is traveled in the city.

One of the large companies told us, "We cannot use electrics because our vehicles travel about 80 to 85 miles a day." When we surveyed their routes we found they did not travel over 20 miles a day, and this was most revealing to this company.

Mr. THORNTON. Certainly for intermittent stop-start type traffic and delivery and other delays there are great advantages.

Mr. YODER. Yes, I think, getting back to your basic question, lots of times these vehicles are overpowered. There's no question about it.

Mr. THORNTON. Thank you, Mr. Chairman.

Mr. BROWN. Thank you, Mr. Thornton.

Mr. Yoder, I think one of the great values of your testimony is indicating the importance of the urban service area as the realm for the electric vehicle, and the importance of operating the vehicle in a systems type of context which is more readily controllable than the present systems for internal combustion vehicles.

We're very grateful to you for your appearance here, and if we do have some further questions, or some members of the committee who had to go and answer the roll call, have questions, I hope you will permit us to address the questions to you in writing.

Mr. YODER. Yes, sir.

[Answers to additional questions submitted to Mr. Yoder follow:]

BATTRONIC TRUCK CORP.
THIRD & WALNUT STREETS
BOYERTOWN, PA 19512
Telephone 215 367-2091

July 21, 1975

Electric Vehicles - Questions and Answers

1. Is there a need for a federal role in aiding the Electric Vehicle industry? Please give detailed, supporting arguments.

There is an urgent need for a federal role in aiding the electric vehicle industry. The electric vehicle industry, for the most part, is owned by small business organizations who have been struggling for the past fifteen years or so to get this industry started. These businesses are using limited resources that are available from business earnings. There are many ways in which the federal government can assist in advancing this industry. These are as follows:

Federal financing with the arrangement of loans with low interest bearing rates.

Many R & D projects, conducted by various departments of the Federal Government, are of prime interest to the manufacturing of electric vehicles and should be made available to these companies. There are contracts with the aerospace industry which the federal government has in the R & D field which could be shared with the electric vehicle industry. There are also manufacturing techniques of interest to the industry such as used to bonderized materials, technical and economic aspects concerning the application of self-supporting plastic sandwich construction to reduce the weight of the vehicles. There are many others such as battery development, use of AC motors, magnetic motors, battery development, use of light weight metals, etc.

Encourage the use of electric vehicles by various federal agencies.

The Clean Air Act of 1970 should be up-dated to take the electric vehicle into consideration. When the electric vehicle can meet transportation requirements of federal agencies of the U. S. Government, these agencies should be given the prerogative of procuring electrics that are substitutable for a vehicle powered by an internal combustion engine. The federal agency should have the prerogative of deciding whether an electric vehicle can conserve energy, reduce operating costs and meet ecology/noise abatement requirements.

Federal laws and regulations are written around a vehicle powered by an internal combustion engine. Recommend that consideration be given of including in these laws and regulations peculiarities of the propulsion system of electric vehicles.

2. What is the current state of the electric vehicle industry?

The electric vehicle industry in the U. S. is in the embryo stage. It is operated by numerous small companies on a piece-meal basis using the limited resources available. They are undercapitalized. The vehicles are often not accepted because of changes required when a new form of propulsion is introduced in a vehicle fleet. We see this embryo industry on the threshold of many breakthroughs as a result of technological advances, the fuel crisis and the ability to provide standard size vehicles that are capable of performing a job similar to vehicles powered by the internal combustion engine.

a) What is its current growth rate?

We believe that its current growth rate is unlimited. Our company is in an excellent position to double and triple our business and produce twenty to thirty vehicles a day. We have postured ourselves and made preparations to manufacture vehicles that are of practical use in meeting urban service delivery requirements. The urban service delivery vehicle is the backbone of our present distribution system. The electric vehicle can make good contributions through conserving energy, reducing pollution/noise problems and operate at low costs.

b) Is the industry limited by markets, capacity, capital, or other factors?

We do not see the electric vehicle industry as being limited to markets or capacity. In the case of industry pertaining to the urban service delivery vehicle, we have been limited by the amount of capital available, for research, development, testing of components to advance the performance of electric vehicles. Other factors which are limiting are the logistic support of vehicles after they are in operation. Reluctance of drivers and mechanics to change their ways of operation from that of vehicles powered by an internal combustion engine. The same type of logistics support is needed for the electric vehicle that is provided for the internal combustion engine. There is no such support system available today. This fact has been a limiting factor in obtaining acceptance of an electric vehicle to meet transportation requirements.

3. What are the best means of procurement for vehicles in order to insure that a fair mix of companies will be able to participate?

We suggest that transportation requirements be categorized in the manner in which they are to be satisfied such as: private transportation; public transit use; distribution of products; utilities; public service (cities, towns and townships); security patrol, etc. With each category or requirement the following should be established:

- Number of passengers to be moved.
- Tons of cargo to be moved.
- Distance to be moved.
- Number of stops/starts.
- Number of days of the week the vehicle is to operate. Any peculiarities that would present unusual problems.

After the detailed requirements are known, the types of vehicles for procurement can be established, i.e., trucks, buses and passenger cars. The procurement of the individual types should be on a negotiated basis with selected companies that have expertise in manufacturing the type vehicle.

a) Will low-capital companies be able to compete in straight competitive bidding, in the sense of being able to finance their bids against possible future sales and subsequent recovery of set-up costs?

No. Low-capital companies will not have sufficient cash flow to procure components, machinery, jigs and pay personnel on a timely basis. A provision should be made to provide progress payments to low-capital companies, such as, 10% upon award of contract; 25% upon acceptance of production model and 65% upon acceptance of vehicle for delivery.

b) Would loan guarantee provisions better enable such companies to raise needed capital?

Yes. A loan guarantee with low interest payments would greatly assist companies in meeting their obligations.

c) Will patent provisions, delivery schedule, or contract penalty provisions inhibit particular kinds of companies from participating?

Patents already established by a company will have to be protected. New patents awarded belong to the company developing and applying for a patent. These provisions can be specified in the contract. There should be no penalty provisions that will add further burden to low-capital companies. The contract penalty has had adverse financial impact on our parent company, the Boyertown Auto Body Works, in manufacturing vehicles for the U. S. Postal Service. We were unable to meet production schedules because of events that were beyond the control of our company. Our experience with penalty clauses has not contributed to the overall well-being of low-capital companies.

d) Should there be a specification that fixed numbers of vehicles must be supplied by companies less than a given size--and/or that fixed numbers of vehicles in given price ranges should be purchased--in order to ensure participation by a broad range of companies?

In order to ensure participation by a broad range of companies we recommend that the purchase order specify the type of vehicle, i.e., van, giving its size, bus, giving its passenger carrying capacity, or a passenger car. The manufacturer should be given the opportunity to specify the price of the vehicle. The manufacturer to have the option of increasing the price over a period of time due to inflation if delays occur beyond his control.

e) Would excessive relaince on small business tend to waste the productive capacity available from the large auto manufacturers, and unnecessarily increase costs of initiating a strong electric vehicle industry?

No. The industrial network of the United States was started and built up around small business activities. These same small business activities are in being and have the expertise to produce vehicles. They may need financial assistance. With regard to the urban service vehicle, the large automotive manufacturers are not prepared to produce the specialized type of vehicles that we are currently producing for them. This is because of the limited volume since they are geared to mass produce the vehicles with the same specifications.

f) What change in safety or import regulations may be necessary to enable a variety of companies to participate?

None. A compromise in safety regulations will be another factor for the consumer to use in not accepting the electric vehicle. Therefore, we are not recommending that the safety rules be relaxed.

4. What are the prospects for consumer acceptance of a limited-performance vehicle?

There is reluctance on the part of the consumer to accept a limited-performance vehicle. The consumer is used to the performance of a vehicle powered by an internal combustion engine. He stacks this performance against a vehicle powered by other propulsion systems such as the electric vehicle. If the vehicle does not perform in the same manner as he is used to he finds fault with it and will develop many reasons for not wanting to use it. The consumer today is enlightened--discriminating. These are the reasons why we had to improve the performance of our electric vehicles by a factor of 2 in the past year or so. The costs of an electric vehicle will be higher and the consumer is expecting just as much from it in the way of performance as a conventional vehicle powered by an internal combustion engine.

5. What are the key institutional barriers to the introduction of electric vehicles--such as utility rate structure, urban design, traffic management schemes, etc.? What are the chances that these barriers can be removed, and what are the best means for doing so?

We do not see major institutional barriers as a deterent to electric vehicles. One of the greatest barriers is the "reluctance to change" using a new type of propulsion system. There is a requirement for newly trained personnel such as electronic technicians and drivers to understand the electric vehicle propulsion system and obtaining the required logistic support to keep them operating. This includes fuel, oil and the required parts. Many drivers insist on a high performance engine that can be operated at high speeds with little consideration to cost and energy consumption. They do not want to readjust their thinking to an electric vehicle that can not be cowboyed. We do not see the utility rate structure as presenting any unusual barriers. The design of our vehicle is the same as our conventional vehicle. We do not see a problem in this regard. The traffic manager may have to be more careful in planning his route structure to obtain the maximum performance of the vehicle with one battery charge. This latter item is more of an inconvenience rather than a deterence to the average traffic manager.

6. Will provision of maintenance facilities for electric vehicles be a major problem in their wide-spread adoption?

   At the present time maintenance facilities are planned for the support of internal combustion engine vehicles. It is our contention that once a technician is trained to make the necessary electronic repairs, maintenance facilities should not present any unusual problems. There are far less facilities required for the repair of an electric vehicle than that of a vehicle powered by an internal combustion engine. There are no spark plugs to change, no timing required for the engine, valves to adjust, oil to be added, liquids maintained in the radiator and maintenance of an exhaust system. The electric vehicle will require less maintenance than a vehicle powered by an internal combustion engine. We believe that the user of an electric vehicle should make provisions for maintenance together with a facility to charge the batteries. A battery charging facility should be designed in such a manner to change the batteries to meet the OSHA provisions and permit changing a run down battery with a freshly charged battery in the same time that it takes to fill a fuel tank.

7. Could the National goals be best met by means of a cooperative effort among the large and small manufacturers--for example, through the production of chassis and other components, respectively?

   Yes. We have taken position that the National goals can be achieved through a cooperative effort among large and small manufacturers. Our current plan calls for the use of components from the large automotive manufacturers including the availability of chassis. In manufacturing our Minivan model, we procured the components from the automotive industry. For some of the larger vehicles it is our plan to procure the bare chassis from the automotive manufacturer. We believe there is considerable information regarding testing and other knowledge that the large automotive manufacturers have accumulated. This information could be passed on to the small manufacturer to reduce costs and avoid delays in the manufacturing process. It is recognized that much of this information will be most difficult to obtain since the information is considered to be proprietory and therefore falls into the limited access category.

8. Is the time scale of the program appropriate? Should phase 1 (conventional chassis) be eliminated or compressed, in view of the current state of the industry?

   Yes. We believe the time scale is now and should not be delayed. In our urban service delivery vehicle market, we estimate that 78% of the user requirements can be satisfied. In five years we believe this number can be increased to 82%. A drawn out time scale will not be advantageous to industry. It would merely delay plans to expand into this important market. Our vehicles are intended to conserve energy, operate pollution free at low costs. In light of the critical fuel situation we do not consider it desirable to delay or draw out the time scale of H.R. 5470.

9. What are the special safety problems?

There are no special safety problems with our urban service vehicles. Each vehicle is standard size and is manufactured to meet the Federal Motor Vehicle Safety Standards.

a) Are electric vehicles safer in some respects, so that current vehicle regulations might be relaxed?

Our electric vehicles are just as safe as the vehicles powered by internal combustion engine. They can not be cowboyed and once the power pedal is depressed, the vehicle will operate automatically. The driver does not have the opportunity to spin wheels and accelerate to the point where extreme safety conditions exist. Electric vehicles are designed to accelerate rapidly and mix in traffic at safe speeds without endangering the lives of occupants.

b) Are there hazards (as sulfuric acid spills...) that ought to be specially addressed?

During the past thirteen years that we have been manufacturing electric vehicles we have not encountered sulfuric acid spills that need to be specially addressed. We have designed our vehicles specifically to preclude accidents pertaining to sulfuric acid. The batteries are located between the front and rear axles to the rear of the driver. This location provides protection from damage in the event of front or rear end collision. The battery cases are completely isolated from the interior of the vehicle, its occupants, by a continuous metal barrier to prevent the cases from penetrating the compartment of the occupants in the event of impact or roll-over. The design of the battery cases, their location and installation in the vehicle, provides adequate ventilation to preclude hazardous accumulation of hydrogen gas during recharging operations. The entire battery system is patented and one of the prime considerations in mounting the batteries in the vehicle was a safety consideration.

10. For long-distance transport, should we take the "Car (E-V)-train (E-V)" -- or other mass-transit -- approach rather than using petroleum to meet the extended range?

We believe the electric train should be used as a means in meeting long-distance transportation requirements, rather than the use of petroleum to meet these requirements.

a) Or, should we have electrified road-ways? (These would have the advantage of eliminating energy wasted in transporting the weight of batteries).

We do not see the need for electric raod-ways. Our electric vehicles are capable of operating along side of vehicles powered by internal combustion engines. Eventually, for the lighter vehicles, when the exotic batteries will come into being they will provide range, be light weight and not detract from the weight carrying capability of these vehicles. Electrified roadways would be extremely expensive and would limit the number of vehicles that could be accommodated.

b) Should electric mass transit be incorporated into the demonstration program:

We recommend that the electric mass transit requirement be treated as a separate problem and not be incorporated in the demonstration program. We believe that the electric mass transit problem should be considered with the overall mass transit requirements. This program can be administered by the mass transit offices of the D.O.T.

c) Please comment on the possible role of the fuel cell.

We have no experience with the fuel cell. The fuel cell when fully developed will most likely be a valuable energy source. The Department of Army, U. S. Army Mobility Equipment Research and Development Center, Ft. Belvoir, Virginia 22060, Office Designation AMXFD-EA has experience with fuel cells. We suggest that any information that the Department of Army has be shared with the electric vehicle users and with your sub-committee.

11. What are the basic objectives of technology demonstration programs, and what general criteria must be recognized in establishing and planning such programs?

The basic objectives of technology demonstration programs should be to equip electric vehicles with the latest componentry and demonstrate their operating capabilities, practical everyday usage to ascertain fuel conservation, pollution/noise abatement and the economy of operations. The electric vehicles should operate in a fleet consisting of ten to twenty vehicles that are manned by fully trained personnel (electronic technicians and drivers) and complete logistic support for their operation. This fleet of vehicles should be operated along side of a fleet of vehicles powered by internal combustion engines to ascertain achievement of the objectives.

a) Given the above general objectives and criteria, exactly how do they relate to the proposed E-V program?

By implementing the above objectives the E-V program will provide positive proof on the practicability of electric vehicles performing urban service type delivery tasks. This proof is required to convince potential users of their practicability in achieving the overall objectives.

b) What schedule (time) and size is appropriate for the E-V program? Why? Some of the witnesses suggested one and three years were too short for the two phases of the demonstration program. Given the current state of the technology, what real accomplishments are possible within this time frame?

The time scale outlined in H.R. 5470 is satisfactory and appropriate. Our company has the capability to produce the urban service type vehicles for this program. A delay or stretch out of the demonstration events not considered conducive to companies motivated in the use of electric vehicles. We believe the objectives specified above can be accomplished in the time span specified. Appropriate reports can be made to Congress and the public on the achievements obtained in the demonstration by the various types of vehicles. A delay in implementing the program will allow additional time for foreign companies to invade the U. S. with their products which they have done with the small automobiles powered by internal combustion engines.

c) If the program were delayed until advanced batteries were available, what would be the benefits of the program? How would these benefits differ from those of an earlier program? What would be the costs and disadvantages of such a delay?

We do not feel that the benefits would be any different if advanced batteries are available, except that the vehicles could travel farther on a battery charge. The battery compartment on our vehicles is designed to accommodate advance batteries when they become available. In the aerospace industry if the U. S. would have waited to test aircraft with exotic fuels, not much in the way of advancement would have been accomplished. We believe that if the aerospace industry had waited for these fuels to come along, the U. S. would have had a major set back and our country would not be a leader in the aerospace field. Delay in go ahead cannot be measured in dollar costs. The disadvantages are further procrastination, further discouragement on the part of manufacturers and users and an opportunity for foreign nations to recapture leadership in this segment of the market.

d) What would be the advantages and drawbacks of having a demonstration program proceding in parallel to advanced battery development? What time scale is likely and reasonable for each?

The availability of an advanced battery system is uncertain. The completion of an advanced battery system has been slipping and each time it is extended to a future date. Assuming an advanced battery system may be available in 1980, if a demonstration program is geared to its availability, it could have a multiplying delaying affect on the remainder of the industry. We can see advantages in a demonstration program proceding in parallel to advanced battery development providing the battery development would not be the pacing factor.

e) What are the non-technological benefits of the demonstration program; could they be realized with today's batteries?

We envision that H.R. 5470 will be the catalyst to encourage greater use of propulsion systems other than internal combustion engines. Moreover, we believe that the logistic support will be established to maximize the use of electric vehicles using batteries that are available today. Another non-technical benefit we see is that the psychological barrier of accepting a new propulsion system such as electrics will be overcome and eventually it will be accepted as a normal mode of propulsion for urban service vehicles.

f) How, exactly, does current cost-effectiveness relate to the objectives of the demonstration program? How would your response be affected by given future cost increases in petroleum; in cost decreases in electric vehicle components and manufacturing?

We believe that the cost effectiveness of the electric vehicle program can be directly related to the demonstration program. The more vehicles on the road the more cost effective they will become. There will be more experience in operating vehicles, logistic support systems will begin to be provided with demand from the operators. We believe the greater experience with electric vehicles will assist in reducing overall cost aspects.

12. Should H.R. 5470 include, perhaps as an independent phase, hybrid vehicles suitable for longer-distance travel? What type of hybrid systems would benefit from a Government-sponsored demonstration program, and in what time frame?

We do not see a requirement for a hybrid system to use on our urban service type vehicles. The hybrid system is different in design and will operate under different parameters than those required to meet the transportation requirements for distribution systems that are employed in inner cities where trucks and buses provide the means of transportation. The hybrid system is more applicable to open highway driving. We recommend that it not be considered as an independent phase of H.R. 5470.

13. Should we include a rental, cooperative or leasing component in the program--in analogy to that of the Witkar in Amsterdam?

We strongly recommend that leasing of the vehicles, including the batteries and charger in H.R. 5470. This will enable the customer to take advantage of the electric propulsion system without a large outlay of cash. The modest monthly payments will enable paying for the vehicle over a period of eight years. Moreover, leasing will preserve the company's cash for other uses. We believe that leasing will have a strong influence in marketing the electric vehicle.

14. Just how severe is the problem of "mix" (E-V's with ICE's) from a safety viewpoint for the demonstration vehicles? Please document your answer.

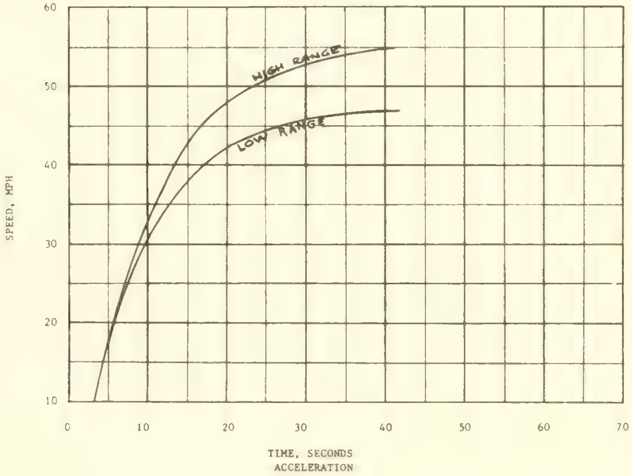
In the fifteen years of experience with electric vehicles we have not encountered a safety problem with our urban service vehicles. Our vehicles meet published safety motor vehicle safety standards. At the present time we have 122 vehicles that are operating along side of conventional vehicles--they do the same job and have not encountered performance deficiencies that are related to the safety aspects of the vehicles. Our vehicles will accelerate from 0 to 30 miles an hour in 9.1 seconds and have a top speed of better than 55 miles an hour. I am enclosing the performance chart of our Minivan to show what it can achieve. In summary, we do not believe there is a problem mixing the electric vehicle with comparable vehicles powered by an internal combustion engine, providing their performance is up to required standards.

BATTRONIC TRUCK CORP.
Division of Boyertown Auto Body Works
BOYERTOWN, PENNSYLVANIA 19512
Telephone (215) 367-2091
BATTRONIC OF BOYERTOWN

Performance Summary Minivan
6440 lbs. (2921 kg) GVWR
112 volt DC System

SPEED - MPH (KM/H)	10 (16.1)	20 (32.2)	30 (48.3)	40 (64.4)	47 (75.6)	50 (80.5)	55-60 (88.5-96.6)
RANGE -							
HI Range - Miles	54.2-59.0	48.8-53.2	42.0-46.5	34.0-38.0	27.7-31.3	25.0-28.0	29.2-22.8
(KM)	(87.2-94.9)	(78.5-85.6)	(67.6-74.8)	(54.7-61.2)	(44.6-50.4)	(40.2-45.1)	(30.9-36.7)
LO Range - Miles	61.0-65.5	54.2-59.0	45.6-50.5	36.3-41.0	29.0-33.0	---	---
(KM)	(98.2-105.4)	(87.2-94.9)	(73.4-81.3)	(58.4-66.0)	(46.7-53.1)		
ACCELERATIONS - IN SECONDS							
HI Range	3.1	5.7	9.1	13.3	19.0	23.2	41.0
LO Range	3.1	5.7	9.6	17.2	42.0	--	--
ENERGY (electricity used)							
HI Range - KWH/Mi	.83	.95	1.08	1.26	1.44	1.52	1.70
(KWH/KM)	(.52)	(.59)	(.67)	(.78)	(.89)	(.94)	(1.06)
LO Range - KWH/Mi	.71	.85	1.00	1.13	1.35	--	--
(KWH/KM)	(.44)	(.53)	(.62)	(.70)	(.84)		

Performance Characteristics
Mini-Van
6440 Lb. (2921 kg) GVWR
112 volt DC System



Performance Characteristics
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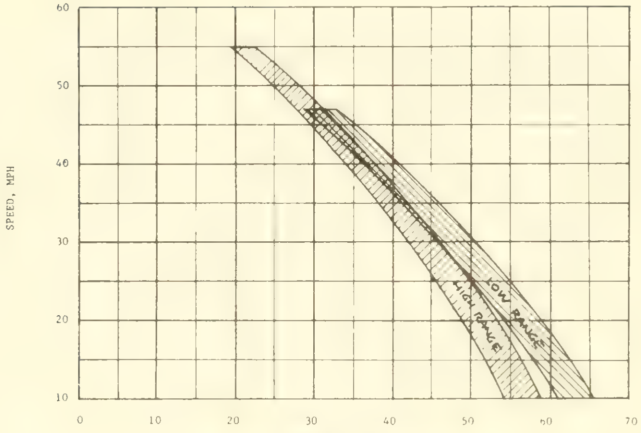
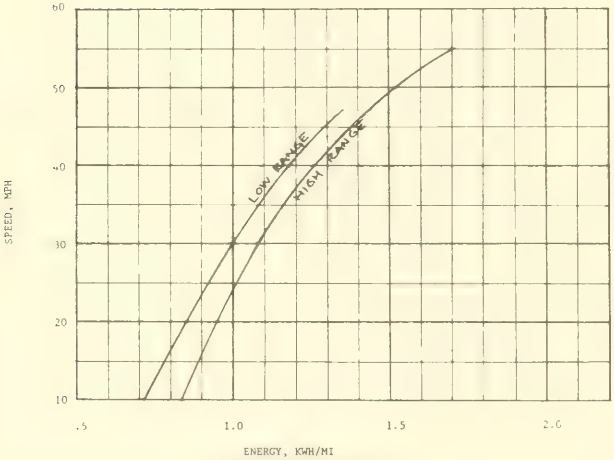


RANGES SHOWN ARE CONTINUOUS, NON-STOP DISTANCES RUN TO AN 80% BATTERY DISCHARGE.



ELECTRICAL ENERGY CONSUMED
ENERGY SHOWN IS ELECTRICITY PUT INTO THE CHARGER

Mr. Brown. Thank you very much for your testimony. The subcommittee will stand in recess until the call of the Chair.

[Whereupon, the subcommittee recessed at 12:30 p.m., to reconvene at the call of the Chair.]

APPENDIX I

Additional Statements for the Record

Raymond N. Auger & Co., Inc.

BOX 2841, ASPEN, COLORADO 81611 TELEPHONE 303/925-4698

June 27, 1975

The Honorable Mike McCormack
Committee on Science and Technology
U.S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

JUL 1 REC'D

Dear Representative McCormack:

While I strongly endorse the intent and methods of HR 5470, the electric Vehicle Research, Development and Demonstration Act of 1975, I would like to suggest improvements in the language of the bill which would broaden its scope in a few important respects.

First, under DEFINITIONS Sec. 4 (1), I would like to propose that the language be altered from: "The term "electric vehicle" means a vehicle which is powered primarily by an electric motor... etc." so as to read instead: "The term 'electric vehicle' means a vehicle which can be at times or continuously powered by an electric motor.... etc." This change would permit the bill to fund the development of vehicles which would be electrically powered in urban situations, but combustion-engined on highways or in open areas beyond the range of electric vehicles. At the present time, the thinking of electric car designers, and the implication of this bill, is that the electric car will be a second car. However, if the dual-engine vehicle becomes widely used, we can have one car able to satisfy the low-noise and low-pollution characteristics of the electric car in city traffic, while retaining the long-range virtues of the combustion engine for great distances. See attached further description of such a vehicle.

I would also like to suggest that under DEMONSTRATION, Sec. 7, (c) (1) that this paragraph be altered to read: "for the introduction of such vehicles produced under subsection (a) into the vehicle fleets of State and local governments and Federal agencies and also for use in public transportation systems such as taxi, jitney or rental car services (which may be operated or in part owned by such governments and agencies;)*".... The reason for this proposed change is apparent: if the purpose of the act is to provide demonstration of electric vehicles, this is best done in a manner which allows as many people as possible to observe their performance, and some type of public service performs this best. The use of electric vehicles in public transportation systems also satisfies the need for obtaining consumer reaction to electric vehicles.

I would also like to suggest an addition to INCENTIVES AND ASSESSMENTS, Sec. 9, (c). The language I would like to propose is: "Such studies and research shall include means for charging or changing batteries along public right of ways, or of obtaining electric power from low-voltage conductors along public right of ways for recharging or propulsive purposes." The attached Fig. 1 illustrates a guideway-conductor means for electric cars. Such electrified guiderails would extend car range and increase battery life.

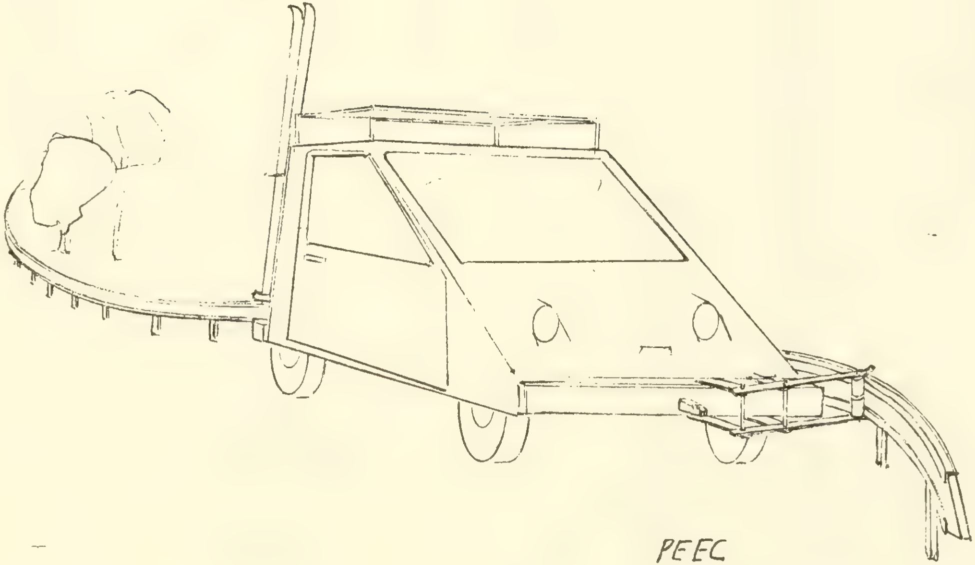
*phrase in parenthesis may be struck out

Finally, I am not in complete agreement with the idea of using existing American automobile chassis for the first phase of the program. While I understand the negative implications of altering foreign cars in a way which might make them more competitive in the US market, at the same time, I think that it would be an error to prevent the use of a small number of foreign cars for experimental purposes. For example, there are no very light-weight 4-wheel drive US-made cars. In many areas under the US flag, a 4-wheel drive vehicle is very desirable, and in many of these areas, urban air pollution is a problem. Having a small 4-wheel drive electrified car would be desirable in these areas, but it would be impossible to demonstrate such a vehicle with favorable characteristics using available US-made 4-wheel drive cars. For the above reason, I would suggest that the bill's reference to the use of American cars be modified in a way which would permit the use of a small number of foreign-made cars. After all, the purpose of this bill is research and demonstration, and if it can be shown that a car configuration being built overseas is superior than one being built in the US, then it is to our national interest to observe this fact so that we can intelligently respond to it with improvements over it. If the intent of the bill is to enable the purchase of a few thousand as part of its first phase, then the purchase of 2% of these with foreign chassis would seem to be appropriate for whatever educational function might be derived.

I remain interested in being of service in any manner which you may wish to suggest to advance the concepts put forth in your proposed legislation.

Sincerely,

Raymond N. Auger



PEEC
Guideway - Powered
Electric Car

Fig. 1

R. Auger 6-9-75

THE GAS-ELECTRIC CAR

The gasoline and/or electric powered car has many features to recommend it:

- For low speeds, short trips and for stop-and-go urban driving, the use of electric drive permits instant starting and excellent acceleration.

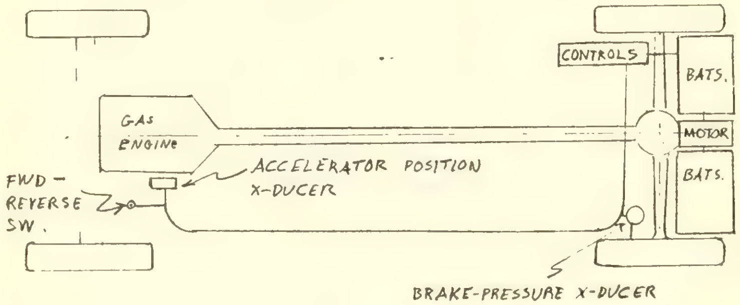
- For higher speeds (above 30 mph) and for long-distance travel, the use of the gasoline engine enables the batteries to be recharged by using the electric motor as a generator.

- On steep hills, both engines can be used.

- Because gasoline engines generate the most air-pollution per mile when idling or when cold, and because they operate inefficiently at low speeds, the use of electric power for urban driving both eliminates exhaust pollution and improves gasoline milage because the gasoline motor is used only on roads on which it can operate efficiently.

- Cars with full gas-electric conversion have no transmission, starter or generator, consequently, their engines operate more efficiently. Cars built as gas-electrics cost no more than all-gas cars because of the elimination of the transmission and starter. Gas-electrics can also use the electric motor as a regenerative charger during coasting and braking, increasing electric-power range approximately 25%.

- Gas-electrics have side benefits: the ability to use one power mode if the other fails, as a reliability asset; and the ability to use the motor as a generator of 120 volt power as an emergency power source for 3 to 7 kw needs.



Raymond N. Auger & Co., Inc.
RA 10/8/75
BOX 2841. ASPEN. COLORADO 81611

MEMORANDUM TO TRANSPORTATION CAUCUS MEMBERS 5/17/75

From: Raymond Auger
Alternatives Re-Evaluation Committee

Dear Caucus Member:

Because the time in which the Citizens Transit Design Caucus must do its work is so short, I am taking the liberty of communicating directly with all of the members of the Caucus with regard to a new alternative system proposal which appears to be gaining endorsement for additional study. To the extent that this new proposal has been studied, it appears to satisfy the requirement of being "equal or better than" the Malmo streetcar proposal. If this opinion is shared by enough members of the Caucus, you may wish to support proposals for the intensification of the analysis of this new system, and possibly an effort to obtain a preliminary reaction to it by UMTA officials.

The system to be described uses no "new technology". It employs vehicles which are commercially available from more than one source. A few of these vehicles will be here for demonstration and evaluation on May 24 and 25, and you are invited to participate in their evaluation. However, they will be modified in a few important respects to make them suitable for the unique transportation system to be described here. The uniqueness of this system may stimulate UMTA interest in its support.

The vehicles to be used by this new system are small electric cars. They are normally battery-operated and have top speeds in the 35 to 40 mph range. They have a range on a full battery charge of from 30 to 50 miles, and can be equipped with battery voltage indicators that indicate remaining charge in much the same way that a gas guage indicates remaining gas.

Two models of such cars, the CitiCar and the Elcar, are presently being marketed in the US. Both seat two adults, and have been extensively developed over a period of years so that they are well beyond the experimental or prototype stage. They are both commercially available through a dealer network. The CitiCar dealer in Colorado Springs has been persuaded to bring up two cars for our evaluation.

The modifications to be made to these cars to make them suitable for a public transit system are relatively minor, and could be accomplished on an experimental basis in a matter of weeks for the purpose of a preliminary evaluation. The most important modifications to be made would consist of the addition of couplings, front and rear, which would enable the cars to be entrained, and the addition of a guideway follower which would enable them to be automatically steered along a guideway which can be designed in a variety of ways, to be described. In addition to a mechanical coupling, each car would require an electrical coupling which would cause all drive motors and brakes to operate together. An intercom system could also be added to this electrical coupling so that adjacent cars could be in communication, or emergency messages could be transmitted to the entire train by the lead car.

A third modification to be made to these cars would consist of the addition of a device which would enable them to obtain electrical power from either contact strips along the guideway or from overhead wires. Although the cars would have sufficient range on battery power to go to Snowmass from Aspen a few times a day, the use of electrical power from the guideway would enable the cars to operate with fully-charged batteries at all times. The guideway need not extend the entire distance of any route. It would be most desirable on hills and in storage areas.

If a surplus of cars would accumulate at any terminal in the guideway system, professional drivers would entrain as many cars needed at other points in the system, and deliver them there as an empty train. Although the entire guideway system could be fully automated, the matter of automation sophistication would require careful study so as to establish a proper balance between system reliabilty, labor use and operating cost.

Looking at just the guideway system, it can be seen that a number of advantages appear to exist over conventional rail systems: vehicle use will perfectly reflect demand. Two people could use one car in the middle of the night, or 200 people could be on one train of cars during the winter rush hours. As each passenger of a train would have his own door, terminal waiting times for passenger loading and unloading would be very brief. Each pair of passengers would have conversational privacy, and their skis would be on a rack on their own car.

The feature of the Entrainable Electric Car system (EEC) which is most attractive is the possibility of removing the cars from the guideway, enabling their street use as vehicles for bringing people to the guideway and the base of the slopes, as well as for shopping and all of the different uses which people make of cars in the county off-season and in the summer.

There are a variety of ways to enable the cars to be removed from the guideway without economic or physical hazards. I will outline one system, but there are an endless variety of ways to obtain the same ends.

Anyone wishing to use the cars off the guideways, or wishing to act as a driver on the guideways, would fill out a rental contract similar to those used by car rental agencies. These contracts could be mailed out by lodges when confirming reservations, they could be obtained at airline counters or at stores and lodges around Aspen and Snowmass. The contract would require proof of financial responsibility (credit card or cash deposit) and drivers license. Anyone satisfactorily filling out the contract would be given an EEC License. These could be obtained at lodges, stores, etc., with a small charge for processing. The EEC License would be a plastic card with a line for a signature. The card would be machine-readable, so that anyone checking a car off the guideway could do so by either sticking the card in a slot, or by placing it in a special transparent window on the side of the car, so that the card could be scanned by a machine as the car drives by. (Similar identification systems are used on railroad cars and on conveyor belts.) The driver might also be required to sign a "check out" card, so that his signature could be checked by TV with the signature on his EEC license. He would be given a check-out slip, which, when returned whenever the car is brought back to the guideway, would establish the charge for the use of the car off the guideway. This charge would be very large during winter rush-hours, to encourage the return of all cars to the guideway at that time.

Anyone not wishing to bother returning his car to the guideway for the rush-hour could telephone for a pick-up, which would send out a driver to couple with the renter's car to return it to the guideway. A service charge would apply for this pick-up, but the renter would be spared the high charge of keeping a car during the rush-hour.

During the summer and off-season, the rental charge off of the guideway could be varied according to the community's desire to keep gasoline cars off of the streets.

In addition to the system described, other systems could be used which would, for example, require the off-guideway driver to buy a book of tickets which would be collected at the time the car is returned to the guideway, depending on the time the car was removed from the guideway, etc. The system could be entirely electronic or entirely manual.

The guideway design should be the subject of a design competition and experimental evaluation. Among the types of guideways: an elevated wheel-width guideway, high enough off of the ground to permit easy snow removal (3 or 4 feet); a ground-level guideway with guidance provided by a low center rail with a roller-follwer on each car; a fence-defined guideway with follower-tracking of a rail of the fence, etc. Some of these guideways would require special plows or snow blowers to clear the guideway without damage to the guide system. Electrical power could be obtained by overhead wires or contact strips on rails with brushes or contact rollers on each car. There are endless variations in guideway designs, consequently I hesitate to be very specific with regard to structural detail. However, as the wheel loading of each car will be quite low (under 400 lbs), guideway cost should be quite modest. However, further study of possible guideway designs will be required to pin this figure down.

It is impossible to thoroughly compare the EEC system with a bus or Malmo streetcar system because there are so many unknowns in both the EEC and Malmo system. Ignoring those areas for the moment in which there is insufficient data for a meaningful comparision, we can nonetheless look at a number of important factors contributing to the success of various systems to see how the EEC, Malmo and bus systems compare in those areas in which data is available.

First, on the matter of cost, the EEC vehicle cost will be between $1,200 to $1,600 per passenger seat, or between $1.2 and $1.6 million for 1,000-passenger-per-hour capacity. The guideway capital cost, as indicated, is an unknown, but could be as little as $200,000 ($20,000 a mile), excluding bridges and land cost. The reason for the low guideway cost is that an EEC train holding 200 people will have a total of 400 tires, creating relatively low surface loading, wear and erosion, in contrast with a conventional rail system, on which 200 people, at crush loading, would be supported by 16 wheels with very high point loading on each wheel. The rail system, whether a car carries 2 passengers or 100, causes approximately the same system wear per vehicle mile, whereas the EEC system, operating between 50% to 100% of passenger capacity, wears out proportional to passenger-mile, rather than vehicle-mile.

While the EEC system will have higher maintenance cost than either a rail or bus system, its income potential will be substantially higher than either of these systems. Also, as the system will require from 1,000 to 2,000 cars to satisfy Aspen's transportation needs, a variety of economic benefits will result from the establishment of routine maintenance proceedures which can be refined to a high degree when there are enough vehicles to provide a statistical basis for repair and maintenance proceedures.

Also, the EEC system can be "phased in" gradually to expose problem areas so that they can be corrected before the system is expanded. The cars of the EEC might even be assembled to some extent in Aspen, providing a new local industry, and giving us high control over the manufacturing process. We could accomplish this by requiring the supplier of the cars to open an assembly factory in Aspen for the cars we would use.

A preliminary comparision of the features of the Malmo, bus and EEC system on which data are available indicates that the EEC system might justify additional study:

	EEC	MALMO	BUS
CAPITAL COST	low	high	low
OPERATING COST	high	low	medium
INCOME POTENTIAL	high	low	very low
POLLUTION (local)	very low	high (noise)*	high (fumes, noise)
AUTO ALTERNATIVE EFFECTIVENESS	very high	low (or unknown)	very low
MODE CHANGE PROBLEMS	none	many	many
SPEED AND HILL CLIMBING	35 mph 16% grade	35 mph 6% grade	35 - 40 mph 12% grade
EQUIPMENT AVAILABILITY	good	fair (quantity limited)	excellent
ROUTE AND SCHEDULE FLEXIBILITY	excellent	poor	good
AVERAGE UTILIZATION	very high	fair-poor	fair
ENERGY PER PASSENGER MILE	low	high	medium
WEIGHT PER PASSENGER SEAT	low	high	low
UNLOADING TIME	very low	medium	medium-high
SKI UNLOADING	very easy	somewhat difficult	somewhat difficult
UNKNOWNS	many	few	none

I hope that the members of the Caucus will have an opportunity to examine the CitiCars on display and available for test drives at Paepcke Auditorium parking lot May 24 and 25. I will be there part of that weekend to answer specific questions about the EEC system, and a salesman for CitiCar will be there to answer questions about that vehicle.

If the members of the Caucus think that the EEC system is worthy of further study, it might be appropriate for the Caucus to vote for: 1) authority for the Alternatives Committee to hire a consultant ($500 budget) with know-how in PRT evaluation to give a preliminary evaluation of the EEC system; and 2) a request for a preliminary response by UMTA on the EEC system. This might best be done by asking (at our expense) an UMTA official to come to Aspen to consider the system and other matters before the Caucus.

If you feel that the EEC system is worthy of further study, please communicate this opinion to your commitee chairman.

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* Based on a comparision of the County's preliminary environmental impact statement and the Colorado Dept. of Health noise standards for residential and commercial noise zones.

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LOS ANGELES, CALIFORNIA 90024
(213) 879-1700 · (213) 477-0066

JOSEPH E. BAIRD
PRESIDENT
AND
CHIEF OPERATING OFFICER

July 9, 1975

Honorable Mike McCormack
Chairman, Subcommittee on Energy Research,
Development and Demonstration
Committee on Science and Technology
B-374 Rayburn House Office Building
Washington, D.C. 20515

Comment on H.R. 5470 - "Electric Vehicle Research, Development, and Demonstration Act of 1975."

Dear Mr. Chairman:

The policies and goals stated in the subject Act are strongly supported. However, the time frame specified within the Act (three years after the date of enactment) for the production of significant numbers of urban passenger and commercial vehicles which are specifically designed for electric propulsion, would essentially eliminate from consideration all battery systems except the existing lead-acid battery system. While the lead-acid battery system is satisfactory for golf carts and other low-performance vehicles, it has reached the limit of its development and can never provide the power required for the range and speed performance needed for a mass urban vehicle.

There are new battery systems under development which promise significantly improved performance over the lead-acid system. Most fall within the time frame of the next decade. However, the Hooker Chemical Division of Occidental Petroleum Corporation has been working during the past 7 1/2 years on the development of a new battery system for load leveling and vehicular application. Testing to date indicates a performance for this new system which will exceed existing lead-acid battery performance by a factor of at least five. The performance of this battery was demonstrated in 1972 when it was used to power a Chevrolet Vega, which has been modified for electric drive, over a course of 150 miles at a steady speed of 50 miles per hour before the battery was discharged. During this test, two laps of the two-mile track were turned at a top speed of 66 miles per hour. Continuing development has resulted in improved battery performance such that, today a similar demonstration would yield a range of 200 - 250 miles at highway speeds.

Development thus far has been totally funded by private interests. Results in the form of operating efficiency and performance, have been better than originally anticipated. Completion of prototype development, plus manufacturing lead time for this new battery system would require only about eighteen months more than the three year time frame of Section 7(a)(2) of the Act.

It is strongly recommended that, in order to take advantage of the greatly improved performance of this new battery system, the implementation date for Sec. 7(a)(2) of the Act be extended 1 1/2 years. Such an extension to permit consideration of the latest developments in battery technology would seem in consonance with the purpose of the Act, and should enhance considerably the chances for enthusiastic reception of electric vehicles by both consumers and industry.

Further information is available by contacting Tazewell Shepard, Executive Vice President, Occidental International Corporation, Washington, D.C. 20006. Telephone 298-6565.

Sincerely yours,

JEB:mb

HIGH PERFORMANCE ELECTRIC VEHICLES THROUGH THE USE OF HYBRID POWER SOURCES

by

H. J. Barger, Jr., 2510 Dover Ct., Woodbridge, VA 22191
J. B. O'Sullivan, 7724 Glenister Drive, Springfield, VA 22152

Partially as a function of the limited availability, modern on-road electric vehicles have not been accepted by the American public because of their poor performance as compared to IC engine powered cars. This performance penalty shows up in several ways that serve to inhibit or inconvenience the vehicle operator., i.e., reduced range, reduced speed, reduced acceleration, and reduced load carrying capability. The obvious component needing improvement is the power source.[1] (Changes in the vehicle to reduce wind resistance and weight or to improve energy transfer efficiency in the drive train are important but should result in only incremental improvements in performance). In order to develop a better power source and thus increase the attractiveness of electric vehicular propulsion, two approaches should be followed: (a) develop superior batteries and (b) utilize two loadsharing power sources (i.e., a hybrid power source). The latter approach is the subject of this presentation.

In Figure IA, the hybrid load sharing principle is illustrated.[2] The prime source, such as a fuel cell, engine generator, or battery, is sized to supply the average load required by the vehicle. The peaking power source which could be a battery or flywheel would supply the power required above the average and would be charged when the load requirements were less than the average. The hybrid makes most sense when there is a widely fluctuating load such as encountered in stop and go traffic. This is analogous to, but of a lower frequency than the duty cycle of a lift truck moving material in a warehouse. Figure IB shows a plot of battery current, which varies with the load, for a 4000 lb. capacity lift truck performing various functions such as ramping, driving, lifting, etc. Note the very high spikes of several seconds duration. These data are summarized in the power frequency polt shown in Figure IC. The average power required is 2-3 KW, but peaks greater than 10 KW also occur.

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[1] "Prospects for Electric Vehicles - A Study of Low-Pollution Potential Vehicles - Electric" Natl. Air Pollution Control Admin. Publication No. APTD 69-52 Prepared by A. D. Little Inc. October 1969

[2] J. B. O'Sullivan, E. J. Dowgiallo, and I. R. Snellings "Hybrid Power Source for Material Handling Equipment" to be presented at the 10th Intersociety Energy Conversion Engineering Conference in Newark, Delaware, August 1975.

Most electric vehicles built to date have been powered by a single battery group which means the battery alone must be able to supply the high power peaks yet have the energy storage capacity necessary to meet the operator's needs. With lead/acid batteries, the only economically viable traction battery available today, the result is a limited-use vehicle with inferior performance. The situation would be much improved with a hybrid power source especially a fuel cell/battery hybrid.[3] A small fuel cell, perhaps 4 KW, would produce power in a pollution-free manner from any of a number of raw materials such as hydrocarbons, methanol, or hydrogen. Since fuel cells are not Carnot cycle limited, a high operating efficiency is possible. Presently available automotive batteries should be capable of providing the peak power required. The range of a vehicle with such a hybrid power source, like a conventional vehicle, would be limited by the size of the fuel tank since the battery would never be completely discharged. The principal drawback to hybrids, cost, can be minimized by selecting the minimum sized prime power source for the intended application.

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[3] E. J. Cairns and H. Shinotake in Fuel Cell Systems II p. 392 (1969), Copyright American Chemical Society.

Voltage-current curves for typical H_2/air fuel cells and automotive lead/acid batteries are shown in Figure ID. The slightly sloping curve for the battery is perfect for the hybrid as little power would be drawn from the fuel cells during the high power pulses.

Although fuel cells and lead/acid batteries have been strongly advocated as an excellent hybrid, they are not the only combination. Table I contains a listing of a number of hybrid candidates with their advantages and disadvantages. It is important to recognize that some hybrids listed here may be built with today's technology and at the same time offer attractive advantages over the conventional IC engine driven automobiles.[4]

In the discussion above, the prime source has been assumed to carry the average load. It may, however, be desirable to rate the prime source (engine or fuel cell) at less than the average and thus withdraw an appreciable portion of the capacity of the peaking power source (battery). The prime source could be looked at as an on-board battery charger. Recharge could occur automatically any time the vehicle was parked. This feature will make electric vehicles much more versatile since the availability of charging stations is likely to be limited in the near future. Ideally a potential buyer of an electric vehicle would be offered a selection of performance capabilities which would match his intended use.

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[4] G. H. Gelb, N. A. Richardson, T. C. Wang, and R. S. DeWolf, "Design and Performance Characteristics of a Hybrid Vehicle Power Train" Paper 690169 presented at SAE Automotive Engineering Congress, Detroit, January 1969.

The foregoing is presented in the hope that the bill under consideration to support the development of electric vehicles will consider the inclusion of hybrids as candidate power sources for these vehicles. The performance enhancement attainable with current technology should increase acceptance and lead to lower component costs as a result of a greater market.

TABLE I - HYBRIDS FOR ELECTRIC VEHICLES

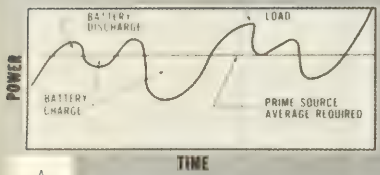
PRIME SOURCE	PEAKING SOURCE	ADVANTAGES	DISADVANTAGES
1. Fuel Cells	Battery	High efficiency, no pollution, long life, range limited by fuel tank.	Cost of fuel cell must be reduced to about $300/KW.
2. Fuel Cells	Flywheel	High efficiency, no pollution, range limited by fuel tank.	High cost, no interfacing experience.
3. Engine Generator*	Battery or Flywheel	Proven technology, relatively low cost, range limited by fuel tank.	Some pollution, reduced efficiency compared to first two candidates.
4. Battery	Battery or Flywheel	High efficiency, no pollution.	Reduced energy storage (range) compared to first three candidates.

*Engine = spark ignition
diesel
turbine
Rankine Cycle
Stirling Cycle

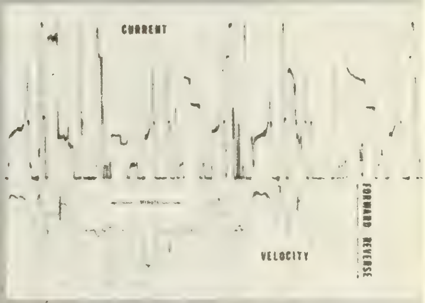
HYBRID POWER SOURCE

PRINCIPLE: AVERAGE POWER SUPPLIED BY PRIME SOURCE
TRANSIENT DEMAND SUPPLIED BY STORAGE DEVICE

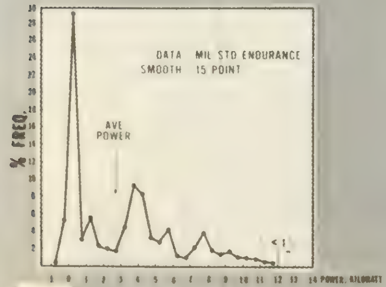
REQUIREMENTS: LARGE RATIO OF PEAK/AVERAGE LOAD
FREQUENT TRANSIENT DEMAND
RAPID LOAD CHANGE



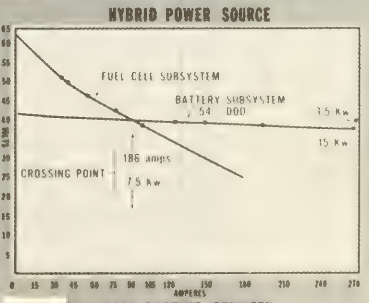
A.



B. CURRENT AND VELOCITY DATA FROM AN ELECTRIC LIFT TRUCK



C. POWER DISTRIBUTION



D. LOAD SHARING BETWEEN FUEL CELL AND BATTERY

ADVANTAGES: DESIGN AND OPERATION AT OPTIMUM POINT
INCREASED FUEL CELL EFFICIENCY
IMPROVED PERFORMANCE
CONTINUOUS OPERATION WITHOUT RECHARGE OR BATTERY REPLACEMENT
LOW EMISSIONS FOR INDOOR OPERATION

FIGURE 1

OTIS ELEVATOR COMPANY

1228 WEST 76TH STREET
CLEVELAND, OHIO 44102

R. BRY
VICE PRESIDENT
DIVERSIFIED OPERATIONS

June 30, 1975
RB-5744

The Honorable Mike McCormack, Chairman
Subcommittee on Energy Research,
Development and Demonstration
U. S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Congressman McCormack:

This is in reply to your kind inquiry giving us the opportunity of submitting written material to be included in the records of the hearing for HR 5470. We offer the following remarks.

We were privileged to attend the subcommittee hearings during the first week of June. As members of the Electric Vehicle Council, we were supportive of Mr. Edward Campbell of the Electric Vehicle Council and at the time of his testimony he asked that several technical papers on electric vehicles, prepared by Otis scientists and engineers, be included in the record.

In addition we would like to include in your record the following statement.

For over 100 years, Otis Elevator Company has been engaged in the movement of people by means of electric motors. Today Otis Elevator Company moves more people daily on its elevators, escalators and electric vehicles than any other company in the world. We wholeheartedly support the intention of the Bill to accelerate and encourage the use of the electric vehicle with its inherent capabilities of moving people without pollution and with a minimum of energy. We agree with the committee members who, during the hearings, expressed themselves as feeling the electric vehicle industry could best be assisted by encouraging the actual manufacture of vehicles by a variety of private enterprises.

The promotion of electric vehicle research and development by governments of other countries in Europe and, notably, Japan, is far ahead of the United States. Japan, for example, has put millions of dollars into research, development and hardware over a period of five years.

HR 5470 is seeking to accelerate the acceptance and development of vehicles by actually purchasing vehicles and putting them in the hands of the users. We subscribe to this approach and believe it will be most effective. Otis Elevator Company manufactures electric industrial lift trucks, electric golf carts as well as escalators and elevators, electric commercial vans, electric buses and electric urban cars. We are aware of the broad spectrum of ways that electricity can move people. Our engineering analysis of the battery powered vehicle field has brought us to the expected conclusion that the larger an electric battery powered vehicle is, the more efficient it is.

The Bill, as it is now written, addresses itself to private passenger vehicles and urban commercial vehicles. We would respectfully recommend that the Bill specifically include urban electric buses. Because an urban bus is of a large size, because it operates on a fixed route, and because it has professional care and maintenance, it is an ideal application for electric vehicles.

The subcommittee is to be congratulated on its understanding of the electric vehicle potential and its ingenious way of assisting a new technology within the framework of private enterprise.

Very truly yours,

OTIS ELEVATOR COMPANY

RBry

RB:k

R. Bry
Vice President-Diversified Operations

MIDDLE ATLANTIC ELECTRIC VEHICLES
322 NORTH STONESTREET AVENUE • ROCKVILLE, MARYLAND 20850 • 301 340-2444

June 10, 1975

Mr. McCormack
Chairman of the Subcommittee on Energy Research,
Development, and Demonstration
U.S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. McCormack:

We would like to express our gratitude for the urgency that you have shown toward the oil problem in America. Our business is as follows. 1) We are the Cushman distributor for the District of Columbia and the greater metropolitan area of Maryland and Virginia. Cushman manufactures several electric vehicles for off the road use and is the largest manufacturer in the United States of small vehicles. 2) We are the Elcar distributor for Washington, D.C. and the state of Maryland.

I would personally like to insert into the printed record of hearings held before the Subcommittee on Energy Research, Development, and Demonstration the following statement.

> The current situation of 99% of all vehicles in use today using gasoline as their fuel source can only create in the long run, the decline and fall of our wonderful country. An available alternative source of power immediately available for certain types of vehicles is the electric vehicle. We must lessen our dependence upon gasoline vehicles and we must do it quickly. The unemployment that exists today coupled with inflation directly parallels the increase in oil and gasoline prices following the Arab embargo.
>
> Our dependence upon foreign oil threatens the national security.

In closing, thank you for your interest in our product. Please don't hesitate to call upon us if we can be of any service to you.

Sincerely,

Laurence H. Burd, Jr.
President

A DIVISION OF GENERAL VEHICLES INCORPORATED

Lockheed
PALO ALTO
RESEARCH
LABORATORY

3251 HANOVER STREET · PALO ALTO, CALIFORNIA · 94304

STATEMENT: Monday, June 16, 1975, by Raymond Capiaux, Vice President, Research, of Lockheed Missiles and Space Company, Inc.,
to
the House Subcommittee on Energy Research, Development and Demonstration
on the
Electric Vehicle Research, Development, and Demonstration Act of 1975
(HR 5470)

Mr. Chairman:

Lockheed welcomes this opportunity to comment on the Electric Vehicle Research, Development, and Demonstration Act of 1975. We are convinced that one of the centerpieces of the National strategy to shift energy use away from petroleum and on to other sources of energy must be the development of an acceptable electric automobile. Indeed, if the effort begins as scheduled, in fiscal year 1976, there will be just sufficient time to achieve that goal by the time the U.S. has exhausted its domestic petroleum resources, about ten years. Moreover, we now have early evidence, based upon research discoveries made in our own laboratories at Palo Alto, California, that a new battery technology, the Lithium-Water-Air battery, may enable us to build electric cars whose performance is competitive with that of gasoline powered automobiles. The existence of this technology, which is quite new, is the principal message which we wish to convey, together with its implications to the proposed legislation and to the prospects for development of an acceptable electric automobile.

Historically, electric cars have not been able to compete successfully with gasoline powered vehicles because of the limited amount of energy which can be stored in existing batteries. One pound of lead-acid battery can store about 14 watt-hours of energy (less at high power levels) against the storage of about 6,000 watt-hours of energy in one pound of gasoline.

While this comparison is manifestly "unfair," it does illuminate the difficulty of competing against gasoline performance with electric power sources. Even though the internal combustion engine/transmission has an overall efficiency of 10 to 20%, the remaining useful energy still dwarfs what is available from the usual electric couples. The Lockheed discoveries show that one pound of Lithium metal, when combined with water and air, will yield just over 6,000 watt-hours of total energy, of which 3,000 watt-hours can be converted into useful electrical energy. Therefore, there exists an electro-chemical reaction whose energy density is equal to that of the gasoline-air heat couple. The Lockheed power cells, moreover, make use of the rapid, direct reaction of alkali Lithium with water, which produces both high power levels and simplicity of the basic reaction. Of course, the power cell system includes more equipment than its basic reactant (or fuel) Lithium metal, so that the final, or overall energy density, will be a number much less than the 3,000 watt-hours or more per pound of Lithium. We feel that a conservative estimate would be about 300 watt hours/pound of system weight. I wish to introduce at this point a report prepared by one of the ERDA laboratories, the Lawrence Livermore Laboratory, entitled:

The Lithium-Water-Air Battery:
A New Concept for Automotive Propulsion
April 9, 1975

which contains the most recent and up-to-date assessment of the Lockheed technology as it applies to automotive propulsion. The Livermore report furnishes considerable technical detail on all of these issues, which I only wish to summarize today. The first implication, then, of the Lithium-Water-Air cells is that it may show the way toward vehicles with extended range, good cruising speed, and significant useful loads. The industry accepts 200 watt-hours/pound of battery weight as the performance goal which will enable us to build a small car (~2,000 # curb weight) with 200 mile range, four passenger capacity, and highway speeds. As we have mentioned, our development should meet these energy density goals.

As we have seen, the Lithium power cells convert Lithium metal and water and air into useful electric power and by-products. In the report cited above, the by-product is Lithium Carbonate, which is conserved in the car and exchanged at a fuel station for new Lithium metal fuel. Thus the Lithium cycles back and forth between the car and a recycling plant and serves as a mechanism to transport electric energy in bulk form. The implications of this aspect are also clear: "recharging" of the car battery is done mechanically, by an attendant in a fuel station, and should take no longer than 15 minutes, as compared to the longer recycling times of most existing batteries.

The process of recovering Lithium from its by-product in a recycling plant will have a governing influence upon the cost of fuel and the total efficiency of the system.

DEVELOPMENT STATUS:

The basic research for the Lithium-Water-Air Battery has been conducted in Lockheed's laboratories since 1969, and fundamental patents have been issued. Various military application development programs have been funded by the Navy, Air Force, and by Lockheed itself, but no products are scheduled to enter production for two more years. With respect to automotive application, Lockheed and the Livermore Laboratory are each preparing proposals to ERDA for exploratory developments over a rather extended time period of at least five years. These carefully coordinated, complementary efforts are appropriate to the resources of ERDA as presently organized and funded, but could be accelerated if ERDA's funding and mandate are increased by the passage of HR 5470.

Lockheed recommends that the three-year span of activity contemplated by the bill be increased to at least five years (preferably 10) and that major emphasis be placed on the successful development of a full performance electric car using the new technologies now available to the art.

Mr. Chairman, I thank you for your time and attention.

R. Capiaux

R. Capiaux

UCID - 16751

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the laboratory.

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THE LITHIUM-WATER-AIR BATTERY:
A NEW CONCEPT FOR AUTOMOTIVE PROPULSION

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ABSTRACT

The Lithium-Water battery is described; it represents a new class of batteries. A modification of this battery, the Lithium-Water-Air battery, is also discussed. The latter provides high specific energy and specific power and thus is a candidate power source for electric vehicle propulsion. The utilization of this battery class for such purpose is examined. The report also touches on other possible batteries in this class.

ACKNOWLEDGEMENT

The information on Lithium-Water batteries which forms the basis of this report, was provided primarily by A.D. Galbraith and E.L. Littauer of the Lockheed Missiles & Space Corporation. We wish to acknowledge Lockheed's invention of the basic battery concept and their pioneering work in this field.

The study from which this report evolved also received input from many persons within the Lawrence Livermore Laboratory and the authors are indebted to them for this help. We are particularly grateful to S.S. Sussman who made a major contribution to the vehicle design sections, and to H.C. Forsberg who contributed in like manner to the section on vehicle refueling and servicing.

SUMMARY

INTRODUCTION

The transportation sector of the U.S. economy utilizes approximately one-fourth of all energy consumed.(1) From an energy use standpoint, this sector is dominated by the Highway Vehicle System (HVS). It alone accounted for 73% of the transportation energy used in the U.S. in 1972.(2) This energy demand is almost entirely supplied by petroleum and thus transportation is a major contributor to our domestic petroleum imbalance.

Energy use sectors other than transportation have an inherent capability for inter-fuel substitution subject to the constraints of capital equipment inventories. This is not true of transportation at this time. Thus it is imperative that alternate energy sources, and propulsion systems to utilize them, be developed for transportation, in particular for the HVS. The passenger automobile is the dominant energy user within the HVS.(3) Clearly the potential for impact on petroleum consumption by developing alternate propulsion systems that use fuels other than petroleum is greatest in the automobile sector.

Electric propulsion is one interesting and challenging alternative to the internal combustion engine. If successfully developed and introduced, the electric vehicle (E.V.) will be energized by electric power plants which can be fueled by coal or uranium. Thus the E.V. can be a multi-fuel but non-petroleum automobile.

Although the concept of E.V.s has been with us for as long as the automobile, it has not been acceptable to the driving public because the available batteries had limited energy and power capacity. This resulted in a vehicle of dismal performance and limited range. In addition, secondary battery recharge times were long, so that the vehicle had to be idled for long periods of time. The key to success for the E.V. is an adequate battery system.

This paper discusses the Lithium-Water-Air battery, a new concept for automotive propulsion. It is based on the Lithium-Water battery developed by Lockheed Missiles and Space Co. for marine applications.(1) If successfully developed, it should make E.V.s practical by providing good performance and long range between recharges. It is a primary battery and thus cannot be recharged in the normal manner. It must be mechanically recharged by replacing the consumable lithium anodes. With proper design this can be utilized to advantage as the battery can be refueled quickly, eliminating the stigma of limited range for the E.V.

DISCHARGE CYCLE

The Lithium-Water battery represents a new class of batteries which employ quasi-passivated lithium anodes. Lithium metal, electrically connected to an iron wire mesh cathode is brought into direct contact with aqueous electrolytes and discharged with high energy and power densities at ambient temperature. The cell reactions are:

Anode: $Li = Li^+ + e^-$ $E_a° = -3.04V$

Cathode: $H_2O + e^- = OH^- + 1/2H_2$ $E_c° = -0.82V$

Net Reaction: $Li + H_2O = LiOH(aq) + 1/2H_2$ $E° = E_c° + E_a° = 2.22V$

During discharge the iron mesh is pressed against the lithium anode. A thin layer of reactive products (nominally lithium hydroxide) forms at the lithium electrolyte interface which exhibits high ionic conductivity and relatively low electronic conductivity. Because of this layer, no separator is needed to protect the lithium. In fact the anode and cathode can be pressed together with pressures on the order of 2 $kg\text{-}f/cm^2$ (30 psi) to reduce internal ohmic losses.

Water serves as the active cathode material in this cell. By discharging an oxidizing agent or by having oxygen (air) at a catalytic surface, the electrolysis of water can be eliminated with an accompanying increase in the battery's energy capacity. Even without use of an oxidizing agent, and based on demonstrated cell performance data, a Lithium-Water battery weighing 220 kg could be built to deliver an energy density of 225 WHr/kg at a power density of 200 W/kg. This battery could power a 900 kg (2000 lb) automobile for 330 km (200 mi). This performance compares most favorably with other available or projected batteries, especially since it is a room temperature system.

The lithium hydroxide concentration in the electrolyte must be controlled for satisfactory battery operation. In the original design for marine application, this was done by adding additional water. This procedure would result in an unsatisfactory weight penalty in an automotive application. Concentration can be controlled more reasonably by adding carbon dioxide to the electrolyte and precipitating lithium carbonate. This reduces the on-board requirement for water. The overall cell reaction thus becomes:

$$2Li + CO_2 + H_2O = Li_2CO_3 + H_2$$

Although provisions can be made for release of the hydrogen, it represents an unacceptable loss of energy. It was stated earlier that the electrolysis of the water could be eliminated by the presence of oxygen (air) in the reaction. This can be accomplished by means of an air cathode. A Lithium-

Water-Air cell has been tested and gives a cell voltage of E° = 3.4V. The energy density of the Lithium-Water-Air battery has been calculated to be 330 WHr/kg at a power density of 200 W/kg and the problem of hydrogen is eliminated. Using carbon dioxide for concentration control as before, the net cell reaction is:

$$Li + 1/4O_2 + 1/2CO_2 = 1/2Li_2CO_3.$$

An additional advantage is that water no longer is consumed in the reaction.

Before the Lithium-Water-Air battery can be developed for traction application, further research is required. An investigation of the protective film must be conducted. It contributes substantially to the internal resistance, and a better understanding of its composition may lead to a reduction of that resistance. Utilization of an air cathode will greatly enhance the energy efficiency of the battery. Improvement of air cathode technology is required. Alternative electrolyte and cathode materials should be investigated with the intent of simplifying the battery operation and providing a precipitant which would simplify the lithium reprocessing. The sensitivity of the battery to impurities must be understood and alternate methods of electrolyte concentration should be investigated. The aqueous battery suggests the possibility of rechargeable non-aqueous analogues. These require investigation.

BATTERY RECHARGE

From an economic and materials conservation viewpoint, it will be necessary to recycle the lithium contained in the battery precipitate. This precipitate will be lithium carbonate or some other insoluble lithium compound. Using present technology, the lithium carbonate would be reacted by one of several methods to produce lithium metal which would then be fabricated into anodes for return to automotive use. The various methods must be evaluated to determine energy efficiency as this will not only affect material conservation but operational cost as well.

The electrical efficiency of the recycle process using the best current practices is 50%. An intensive study is required to determine whether that efficiency can be improved. The propulsion efficiency of the discharge cycle is estimated at 52% so that the overall efficiency of the battery system is 26% when used as a primary battery. Secondary battery systems are more efficient although they do not presently supply the needed performance. This suggests that the ultimate solution is a battery/battery (primary/secondary) hybrid.

AUTOMOTIVE SYSTEM FEASIBILITY

When considering the question of the feasibility of the Lithium-Water-Air battery for automotive propulsion, a number of issues should be considered. One must consider the vehicle design options offered by this battery, the type of performance to be expected, the cost of operation, the servicing requirements, and the fuel distribution system which results. In addition, the nation's lithium resources must be critically examined. We do not want to create a future "oil" problem. Finally, one must be concerned with assessing the impact of introducing such a system as a Lithium-Water-Air battery-powered E.V. Each of these issues must be examined in detail, as each can have an effect on battery development. The vehicle design options will be of prime concern to battery development as they will directly affect its output requirements.

Several battery options are available for E.V. design. These include primary, secondary, and battery/battery hybrid. A preliminary study examined a vehicle powered by the Lithium-Water-Air primary battery aided by a small secondary battery. The secondary battery acts as a power buffer and supplies power for starting, lighting and instrument functions. A 900 kg (2000 lb) vehicle equipped with such a battery system weighing 500 lbs, would have a range of 330 km (200 mi), an acceleration to 64 km/hr (40 mph) in 10 sec, and a maximum sustained speed of 97 km/hr (60 mph).

The range of the E.V. could be extended rather rapidly by a CO_2 recharge, removal of Li_2CO_3, and a change of lithium anode. Refueling need not be tedious if an appropriate modular design is effected. If an additional 29 kg (64 lbs) of lithium (330 km range requires 7.3 kg lithium) is carried, the anode need only be changed every 1600 km (1000 mi). This could be done during normal more extensive vehicle servicing. The advent of this vehicle will require establishing a different fuel distribution system.

The operating cost of an E.V. powered by the Lithium-Water-Air battery is tied inextricably to the cost of lithium and the battery system chosen for the vehicle. At present gasoline prices (which are expected to rise) and assuming 20 mpg (the 1980 goal) the current cost of fuel is 3¢ per mile. For comparison, it is expected that the cost of reprocessed lithium in large quantities will be $1.50 per kg (approximately $0.70/lb). If the battery system is primary then the cost of operation will be 7.4¢ per mile; if it is hybrid with the secondary battery sized for 20 mile range, the cost will be about 3¢ per mile. Other combinations will give different operating costs.

A more detailed feasibility study must be conducted as this will affect the battery design.

CONCLUSIONS

- The Lithium-Water battery can provide energy and power density levels sufficient to provide an electric vehicle with acceptable performance.
- Considerations of cost per mile motivate development of an even higher performance battery -- the Lithium-Water-Air battery.
- Both batteries derive high energy and power from a combination of high thermodynamic potential with novel cell design, utilizing direct anode/cathode contact.
- There is a strong potential for the development of high performance non-aqueous, rechargeable analogs to the Lithium-Water battery.
- Research is needed to improve processes for the regeneration of lithium metal.
- A primary battery with a power buffer makes it possible to design a 2000 lb vehicle with a 200 mile range, at 60 mph cruise speed, and with good acceleration.
- To achieve this superior performance at a reasonable fuel cost, considerable system design effort will be required.

DELIVERY OF ENERGY FROM THE BATTERY

THE LITHIUM-WATER PRIMARY BATTERY CONCEPT

The Lithium-Water Galvanic Cell: A New Battery Concept

A primary battery utilizing the reaction between lithium and water has been developed by Lockheed Corporation for marine applications.(4) The battery is a representative member of a new class of batteries which employ quasi-passivated lithium anodes. In these batteries, lithium metal is brought into direct contact with aqueous electrolytes and discharged with impressively high energy and power densities (compared to other room temperature batteries) when used in combination with a water cathode or with any of several other cathode materials (including air).

The Lithium-Water cell may be described by the following reactions:

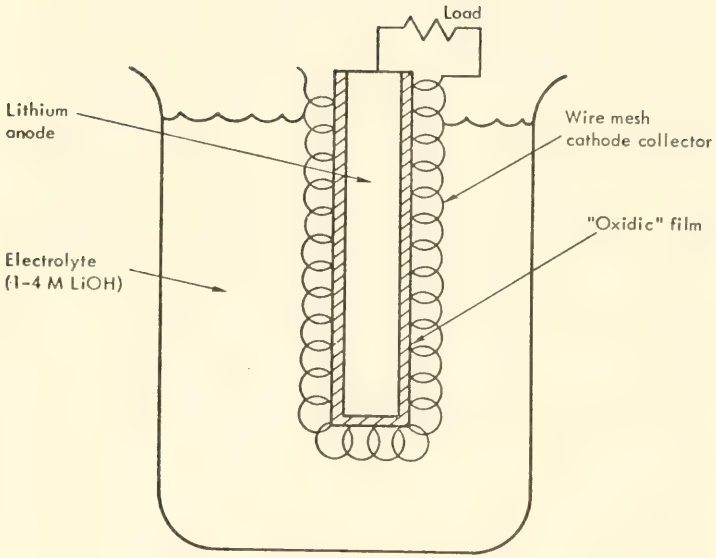
Anode: $Li = Li^+ + e^-$ $E_a° = -3.04V$

Cathode: $H_2O + e^- = OH^- + 1/2H_2$ $E_c° = -0.82V$

Net Reaction: $Li + H_2O = LiOH(aq) + 1/2H_2$ $E° = E_c° - E_a° = 2.22V$

In a simple version of this cell, an iron wire mesh cathode is pressed against the lithium anode, and the leads are connected through a load as shown in Figure 1. The electrode assembly is immersed in lithium hydroxide electrolyte. During discharge of the cell, a thin layer of reactions products (nominally lithium hydroxide) forms at the lithium/electrolyte interface. The layer exhibits high ionic conductivity and relatively low electronic conductivity. Hydrogen evolution, which requires electron transfer, is strongly impeded on the anode surface and occurs almost exclusively (95%) on the iron cathode.

It is the existence and properties of the anode surface layer which give the Lithium-Water cell its novel design. No separator is needed to protect the lithium from corrosion in the presence of water. The wire mesh



Anode reaction	$Li \rightarrow Li^+ + e^-$
Cathode reaction	$H_2O + e^- \rightarrow OH^- + 1/2\ H2$
Net cell reaction	$Li + H_2O \rightarrow LiOH + 1/2\ H_2$
Cell voltage, E°	2.2 V

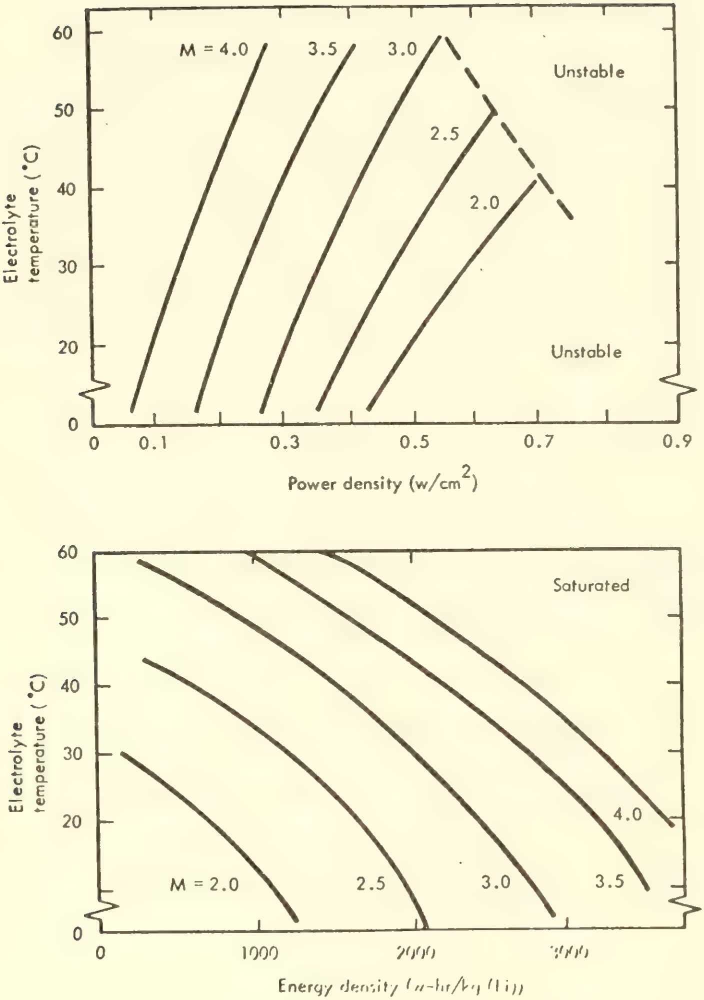
Fig. 1. Lithium/water cell - schematic

cathode may be pressed against the anode with considerable pressure (2 kg-f/cm^2 [30 psi]) without shorting the electrodes. Advantages of this configuration are: (1) the ohmic drop through the electrolyte in the interelectrode gap is essentially eliminated; (2) the close spacing of the electrodes provides enhanced mass transport by diffusion in the electrolyte; (3) constant electrode separation produces time-independent discharge voltage and current. These features result in a stable discharge at high power levels.

The film exists in a dynamic steady state, being continuously formed and dissolved at the lithium/electrolyte interface. Maintenance of the steady state requires continuous cell discharge into an electrolyte of sufficiently high lithium hydroxide concentration (greater than 1.5 M LiOH). With the use of appropriate additives (Lewis bases), the parasitic corrosion of lithium may be essentially eliminated over a wide range of discharge current densities, and coulombic efficiency (i.e., the fraction of lithium utilized in the galvanic reaction) may approach 95%. Upon breaking of the external circuit, the film dissolves and corrosion ensues.

Discharge characteristics are dependent on lithium hydroxide concentration and on electrolyte temperature. At a given temperature, an increase in molarity results in an increase in energy density but a decrease in power density as shown in Figure 2. At a given molarity, increasing the temperature has the opposite effect. Optimum cell performance requires, therefore, control of temperature and lithium hydroxide concentration.

In the Lithium-Water cell, water serves as the active cathode material. However, electrolysis of water may be replaced by the discharge of any of a number of dissolved oxidizing agents, or by oxygen (air) at a catalytic surface. The existence of the protective film on the lithium is not affected.



(Maximum theoretical energy density, 8500 Whr/kg(Li).
Data for cell discharge at 1 volt.)

Fig. 2. Discharge of the lithium/water cell.
Dependence on system parameters.

Comparison with Automotive Requirements and Other Batteries

The performance characteristics of different electric batteries may be compared on a graph of specific power against specific energy (Ragone plot),(5) the power and energy being normalized to the weight of the battery system (Figure 3). In automotive application, for fixed battery and vehicle weight, top speed and acceleration are determined by specific power, while vehicle range is indicated by specific energy. Based on demonstrated cell performance data, a Lithium-Water battery weighing about 220 kg could be built to deliver an energy density of 225 WHr/kg at a power density of 200 W/kg; it would power a 900 kg auto for 330 km (200 mi).

Shown for comparison are Lead-Acid, Nickel-Cadmium, and Nickel-Zinc batteries which fall far short of the required energy density for a 330 km range. The Zinc-Air battery meets range requirements only at unacceptably low power. The Lithium-Iron Sulfide battery shows sufficiently high power density, but battery energy capacity is too low. Molten salt batteries show high potential performance, but present development efforts are plagued by extremely difficult materials problems.

It should be noted that the performance characteristics of automobile internal combustion engines appear in the power density range of 200-300 W/kg and an energy density range of 100 WHr/kg or greater. Only the Lithium-Water and the molten salt batteries fall in this region of the diagram and thus offer the potential for meeting the performance requirements for battery-powered automobiles. In particular, the Lithium-Water battery is the only demonstrated room-temperature system with such characteristics.

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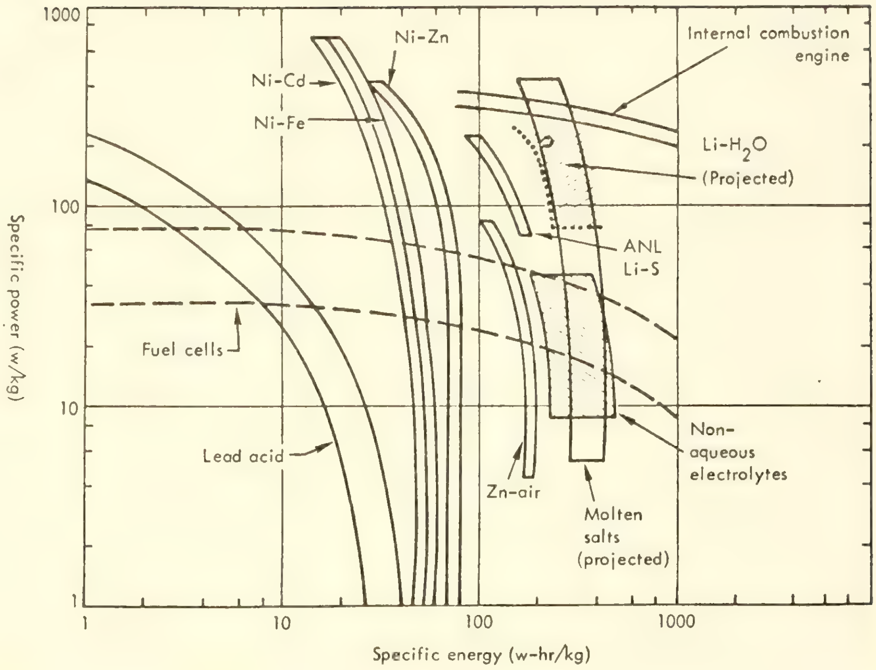


Fig. 3. Performance characteristics of electric batteries

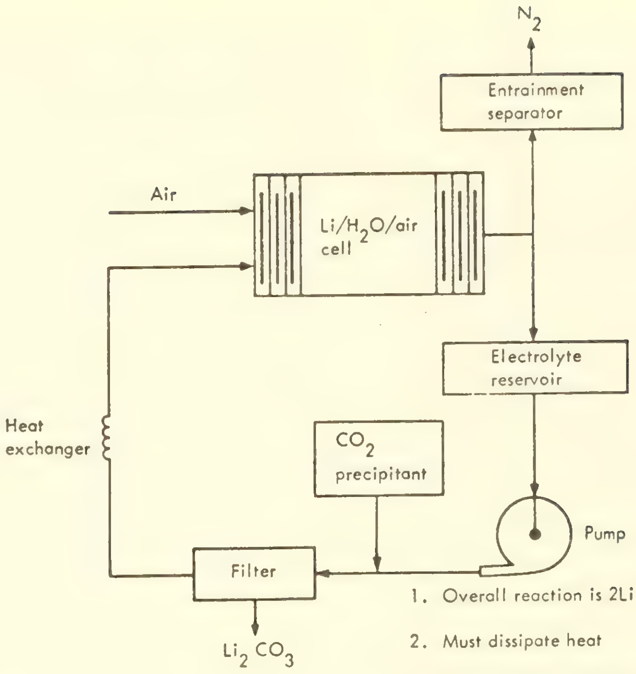
Battery Description and Characteristics

Physical Description and Nature of Operation - Present cell designs provide for control of electrolyte temperature and concentration as indicated in Figure 4. During shutdown periods, the battery is drained and the electrolyte is stored in a reservoir. During discharge, electrolyte is circulated through the battery and through a heat exchanger. Concentration control is effected by precipitation of lithium carbonate with carbon dioxide. The overall cell reaction is:

$$2Li + CO_2 + H_2O = Li_2CO_3 + H_2.$$

Provision can be made for separation and release of the hydrogen gas. However, operation in this mode would represent an unacceptable waste of energy. Recovery of this energy through the use of an air cathode is discussed in a later section.

Advantages and Disadvantages of the Lithium-Water Battery for Automotive Propulsion -- A Lithium-Water battery is competitive with an internal combustion engine in terms of energy and power characteristics. Nonetheless, it is a primary battery and requires periodic mechanical recharging of the reactants: lithium, water, and a precipitating agent (e.g., carbon dioxide). The most densely energetic reactant is lithium; an on-vehicle inventory of 65 kg would be sufficient for 1000 mile range. The heavier reactants, water and CO_2, limit the range but these fluids may be easily recharged. The cost of mechanical recharge of lithium including the economics of lithium recycling and distribution will be considered later in this report. For now, we point out that an increase in energy density for a given vehicle and battery weight will result in a proportionate decrease in operational cost per mile. Thus there is motivation for increasing the performance of the basic Lithium-Water cell beyond the minimum level required for acceptable automotive performance.



1. Overall reaction is $2Li + CO_2 + 1/2O_2 = Li_2CO_3$
2. Must dissipate heat
3. Must add 1/2 mol CO_2 per mol Li

Fig. 4. The basic lithium-water-air system requires heat rejection and LiOH concentration control.

Necessity for a Lithium-Water-Air Battery (air cathode) -- A Lithium-Water-Air cell has been tested, utilizing the following reaction:

$$Li + 1/4O_2 + 1/2H_2O = LiOH(aq) \qquad E^\circ = 3.4\ V$$

Open circuit potential of 2.9 V and cell voltage of 2.6 V at 200 mA/cm^2 have been demonstrated in laboratory experimental prototypes. The prototype cell utilizes a porous Teflon cathode with a catalytic coating. Cell configuration is otherwise the same as with the Lithium-Water battery. Using carbon dioxide for concentration control, the net cell reaction is:

$$Li + 1/4O_2 + 1/2CO_2 = 1/2Li_2CO_3$$

The use of an air cathode is advantageous for several reasons: (1) calculations indicate that the higher cell voltage increases the energy density of the battery to 330 WHr/kg at a power density of 200 W/kg; (2) water is no longer consumed as a reactant, and large on-vehicle inventories are unnecessary; (3) the cathode depolarizer, oxygen, is available from the air, and its weight need not be considered in the calculation of energy density; (4) hazards associated with disposal of combustible hydrogen gas are eliminated.

In a later section on economics of the Lithium-Water system, it is noted that the costs associated with the preparation of lithium metal for recharging the batteries are extremely important. The increased energy per mol of lithium which results from use of an air electrode will be essential if this system is to achieve reasonable economy of operation. Therefore the development of a suitable air cathode will be a necessity for success of a Lithium-Water automotive propulsion system.

RESEARCH AREAS FOR LITHIUM-WATER BATTERIES

Investigation of the Protective Surface Layer Formed on Lithium Anodes in Aqueous Electrolytes

In cells of the Lithium-Water type, the electrical resistance of the anode surface layer contributes substantially to the total internal resistance of the cell. Research is needed to understand the chemical composition, morphology, and mechanism of electrical conduction of the surface layer. With this understanding it may be possible to reduce anode resistance. The nature of the film is strongly influenced by solution side mass transport, electrolyte composition, lithium hydroxide concentration, and certain corrosion inhibitors. Film dopants (from the lithium substrate or from the electrolyte) may also play a role. These areas must be investigated to provide the scientific understanding necessary for the control of film resistance.

Air Electrode Development

The energy efficiency of the Lithium-Water battery is greatly enhanced by the utilization of an air cathode. For this reason, it is important to investigate and advance currently available air cathode technology.

The precious metal catalysts, such as platinum and silver, have dominated other catalysts in the literature. Their enhanced catalytic efficiencies are warranted in military and space applications where cost is not as important as in the automotive field. However, for electric vehicle application, investigation of low cost catalysts(6) such as the mixed transition metal oxides and spinels appear worthwhile. The useful life of air cathodes containing these metal oxides and spinels should be evaluated in the Lithium-Water system with air cathodes.

The most serious problems reported in the literature are documented in relation to Zinc-Air batteries. These include low cycle life, low power density, and tendency of the pores in the separator to clog with zinc carbonate.

In a primary battery system, the air cathode will not be cycled in a reversible mode, so that the life may be prolonged. The effect of this needs to be determined. In addition, the effect of drying the air cathode upon its efficiency must be investigated, since it is anticipated that the electrolyte will be drained into a pump when the car is not in use.

To protect the lithium during prolonged periods of battery idleness, it is currently planned to pump castor oil into the battery. The effect of such a liquid on the life of the air cathode must be determined.

Further, we need to determine whether lithium carbonate will clog the pores of the air cathode similar to zinc carbonate in the Zinc-Air battery. While precipitation with CO_2 and filtration will take place outside the battery, the reaction time may be slow enough that some precipitation will occur within the battery cell.

Alternative Electrolytes and/or Cathode Materials

In addition to water and atmospheric oxygen, Lockheed has discovered a number of proprietary, water-soluble oxidizing agents which may be used as active cathode materials. With such materials, the basic cell design is retained, and the cathode materials are dissolved in lithium hydroxide electrolyte.

At Livermore, a cell has been built which utilizes the reaction of lithium and iodine in an aqueous electrolyte of saturated lithium iodide:

$Li/LiI, I_2, H_2O/graphite$ Open circuit potential 3.1 V

The battery retains the same cell geometry as the Lithium-Water batteries, but a different protective film is believed to be formed. Analogous cells utilizing aqueous solutions of other lithium halides and halogens (including chlorine and bromine) may be possible. These cells obviate the need for a chemical precipitation cycle and for a gas/electrolyte separation step, and may provide actual specific energy and power comparable to the water and air batteries. In addition, the end product of the reaction, a lithium halide, is in the form needed for direct lithium regeneration by conventional industrial processes.

Sensitivity of Battery Performance Characteristics to Impurities

An important area for research involves identifying the sensitivity of battery performance to impurities introduced into the reactants or into the electrolytes. The objective is to predict possible performance losses or hazards resulting from the limits of quality control of the manufactured battery or from the spectrum of abuse which the public would give such a battery.

Alternate Modes of Concentration Control

The method currently considered for the control of lithium hydroxide concentration makes use of carbon dioxide to precipitate Li_2CO_3 which can be filtered off. Other precipitating or flocculating agents should be investigated to determine ease of filtration, materials costs, and economics of recycling. Operation with saturated lithium hydroxide solutions and filtering of solid lithium hydroxide may be feasible if surface layer resistance is sufficiently lowered; this possibility must be thoroughly explored.

Exploration for Rechargeable Analogs of the Lithium-Water Cell

The Lithium-Water battery is one member of a class of galvanic cells which utilizes an anode surface film, formed during discharge, as a cell separator. The film chemically isolates the anode from the electrolyte and/or liquid cathode material,and in some cases provides electronic insulation between the electrodes'metal phases. At least two other members of this class, which involve pseudo-passivation reactions of metals with liquid catholytes, are known:

Cd/I_2 (liq, 120°C), KI/inert metal cathode(7)

$Li/SOCl_2$, $LiAlCl_4$/inert metal cathode(8)

Here I_2 and $SOCl_2$ are used as cathode materials. These cells are not rechargeable.

On the other hand, many rechargeable galvanic cells of convential design have been developed with high specific energy (greater than 150 WHr/kg), using electrolytes based on aprotic, inorganic or organic solvents. Because of the low electrical conductivity of these electrolyte solutions (10^{-3} to 10^{-2}/ ohm • cm), ohmic losses in the interelectrode gap and in mechanical separators are high. Consequently, specific powers of rechargeable cells of conventional design are unacceptably low for automotive applications.

Exploratory research is needed on Lithium/liquid cathode systems which are known to be rechargeable when used with mechanical separators and which are likely to form protective films of the required properties when discharged in the presence of the liquid cathode. Likely candidates for investigation are shown in Table 1. The reaction of lithium in thionyl chloride is illustrative of our interest; it is thermodynamically energetic:

$$8Li + 4SOCl_2 = Li_2S_2O_4 + 6LiCl + S_2Cl_2$$

$\Delta G = -84$ kcal/mole-Li(8)

Candidate systems utilize Lithium anodes, inert cathodes, and:

Solvents	Electrolytes	Cathode Depolarizers
Inorganic:		
$POCl_3$ or	$LiAlCl_4$ or	Cl_2 or
$SOCl_2$	$LiAlBr_4$	Br_2
SO_2Cl_2	$LiBCl_4$	I_2
	$LiSO_3Cl$	
Organic:		
Propylene Carbonate	$LiAlCl_4$ or	Br_2, I_2
	LiBr	
	LiI	

Table 1. Candidate systems for a rechargeable non-aqueous analogue to the lithium-water galvanic cell.

Nevertheless, a protective film forms on the lithium during exposure to $SOCl_2$ which virtually eliminates spontaneous corrosion. In addition, the following cell is known to be rechargeable when used in a conventional cell design:

$Li/SOCl_2$, $LiAlCl_4/LiAlCl_4$, $SOCl_2$, Cl_2/ inert metal cathode.(9)

Should the desirable properties of the lithium surface film be maintained when the separator is removed from this cell, and should electrode polarizations remain low, we would have demonstrated the basis for a rechargeable analogue to the Lithium-Water cell.

A large number of possible cells could be assembled from the several materials listed in Table 1. Other anode, electrolyte, and depolarizer choices also could be made. The recognition that this new class of cells exists opens an entirely new field of potential high energy batteries for investigation.

DELIVERY OF ENERGY TO THE Li-H_2O SYSTEM

NEED FOR Li RECYCLE

Upon discharge, the end products of the lithium-water primary battery probably will be a precipitate of lithium carbonate or other insoluble lithium compound, a small amount of lithium hydroxide solution and possibly some residual lithium. From an economic standpoint, as well as a materials conservation viewpoint, it will be necessary to reprocess these materials to provide for the reservicing of batteries. Environmental consideration also requires that these materials be controlled and not allowed to become a source of contamination.

RECYCLE OPTIONS

Using present technology, wet LiOH or Li_2CO_3 would be reacted with HCl to form LiCl; this would be dried and subjected to electrowinning to produce lithium metal and chlorine gas. The chemical reactions are:

$$LiOH + HCl \rightarrow LiCl + H_2O$$

or

$$Li_2CO_3 + 2HCl \rightarrow 2LiCl + H_2O + CO_2$$

$$LiCl \xrightarrow{\text{electrolysis}} Li + 1/2\ Cl_2$$

In order to close the cycle with respect to chlorine, one may either use the reverse Deacon reaction:

$$Cl_2 + H_2O \xrightarrow{800^\circ C} 2\ HCl + 1/2\ O_2$$

or a two step process:

$$Cl_2 + H_2O \xrightarrow{\text{room temp.}} HCl + HClO$$

$$HClO \xrightarrow{\text{catalyzed}} HCl + 1/2\ O_2.$$

These steps are awkward and may be thermally inefficient.

A more simple reaction has been suggested:(10)

$$Li_2CO_3 + Cl_2 \rightarrow 2LiCl + CO_2 + 1/2\ O_2 \qquad \Delta H = 1.09\ \text{kcal}$$

The heat that must be supplied for this reaction is only 0.09 kw hr per kg of lithium. In addition, the free energy for the reaction increases from -6.6 kcal at room temperature to about -14.6 kcal at 330°C; thus the reaction should proceed well at the higher temperature. We can visualize a process in which the dried Li_2CO_3 is reacted with counter-current flowing Cl_2 from the electrolysis cells, producing dry LiCl feed for these cells. In this manner the chlorine cycle might be closed more cheaply. Similar considerations would apply to LiOH. A detailed study of current industrial practice and of possible alternatives will be necessary to understand this subject and to see whether the economics of lithium recycle can be brought into a realm where use of the battery system will be competitive with other fuels.

ELECTRICAL REQUIREMENTS AND EFFICIENCY

The actual electrical requirements to produce Li from LiCl vary considerably depending upon the type of cell used and whether the cells are heated electrically or by thermal methods. Literature reports(11,12,13) show a range from 28-42 KWhr/kg, whereas the theoretical energy consumption ranges from 14.2-15.2, depending upon the voltage employed. Data from Ref. (11) is shown below:

	Degussa Cell	American Cell
Daily Production (kg)	100 to 200	30 to 60
Cell Voltage (V)	6.1	6.1
Cell Current (KA)	Max. 40	Max. 12
Current Yield (%)	c. 85	c. 40
Energy Consumption (Electrolysis) (KWh/kg)	c. 28	c. 32
Energy Consumption (Heating) (KWh/kg)	--	c. 5 to 10
Total Energy Consumption (KWh/kg)	c. 28	37-42
Theroretical decomposition voltage 3.68 V; theoretical current consumption 3.86 kA/kg; theoretical energy consumption 14.1 KWh/kg.		

Table 2. Cell Parameters

From the figures in Table 2, the electrical efficiency of the recycle process, using best current practice is:

14.1/28 = 50%

An intensive study of lithium and sodium metal production practices will be needed to see whether this efficiency can be improved.

Figures supplied by Lockheed Missile & Space Co. imply the following discharge performance for the Lithium-Water-Air battery in a vehicle.

Electrical energy loss	4465	whr/kg Li
Motor and Pumping cost	1725	whr/kg Li
Available energy for propulsion	6835	whr/kg Li
TOTAL	13,025	whr/kg Li

Battery electrical efficiency is 66 percent, and propulsion efficiency is 52 percent. Thus the overall electrical efficiency of the Lithium-Water primary battery and recycle system is 0.5 x 0.52 = 26%. Comparisons of vehicle system efficiencies are shown in Figures 5 to 9. It may be seen that from an overall efficiency viewpoint, electric vehicle systems of the secondary battery and battery/battery hybrid types are more efficient than internal combustion engine systems. The Lithium-Water system operated as a primary battery, however, would be less efficient.

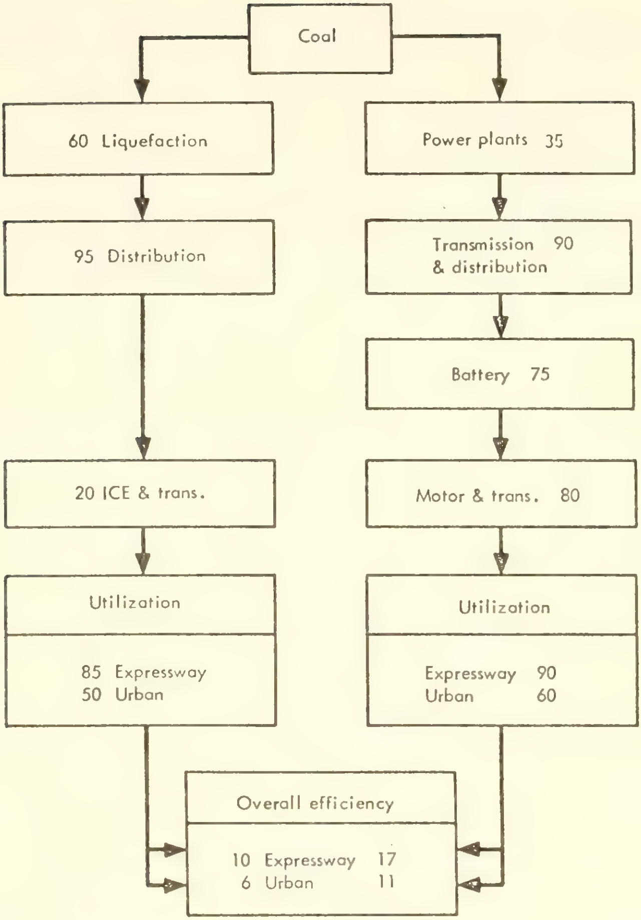


Fig. 6. Comparison of energy conversion efficiencies: internal combustion vs. electric vehicles powered by secondary batteries.

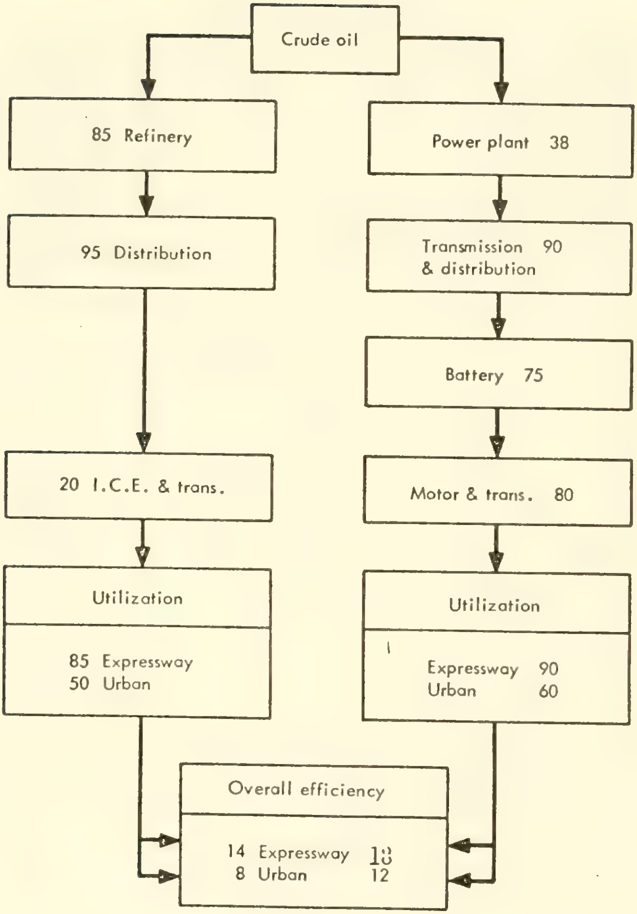


Fig. 5. Comparison of energy conversion efficiencies: internal combustion vs. electric vehicles powered by secondary batteries.

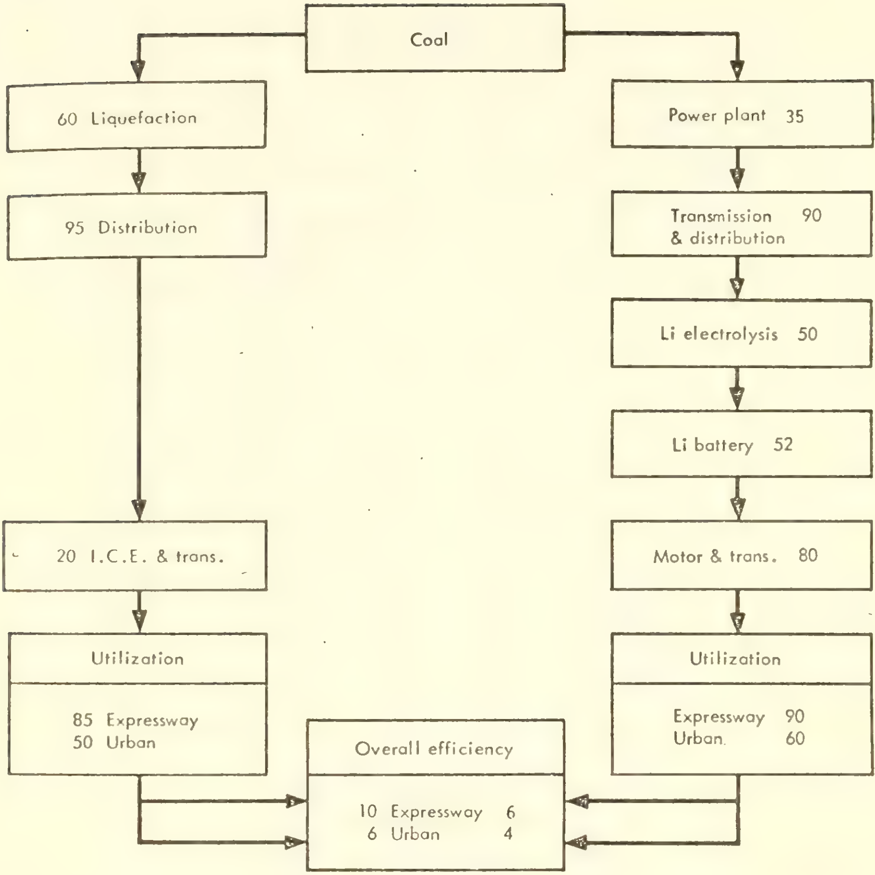


Fig. 7. Comparison of energy conversion efficiencies internal combustion vs. lithium/water representative electric vehicle

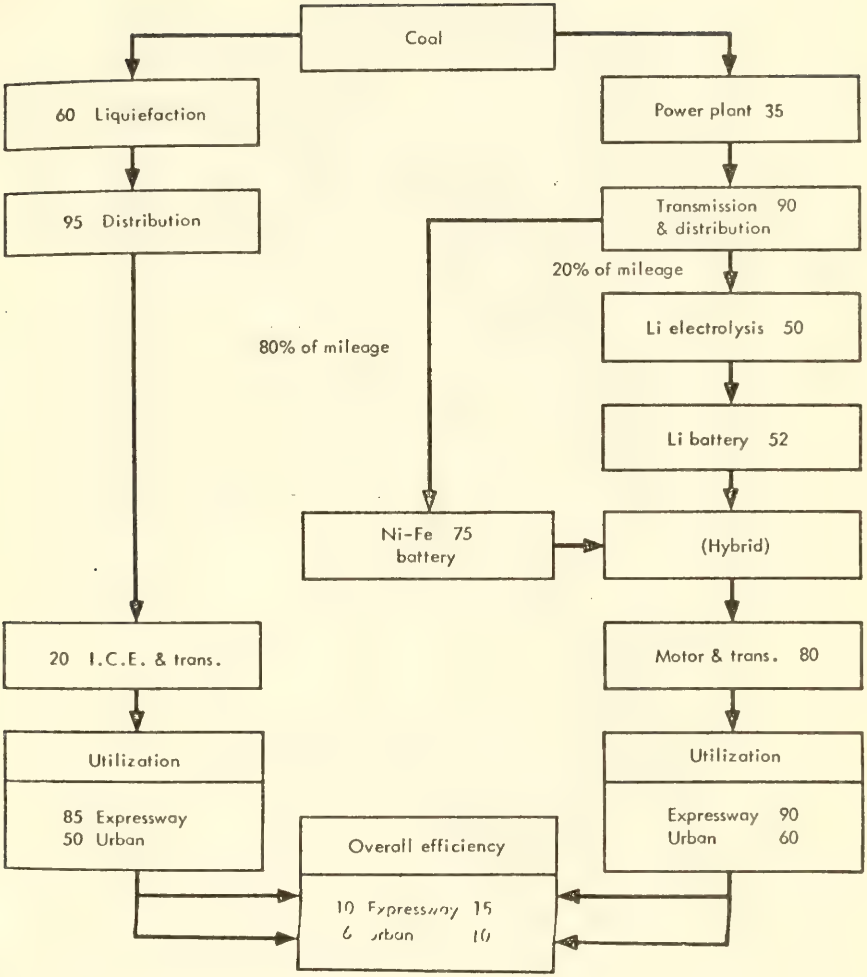


Fig. 8. Comparison of energy conversion efficiencies: internal combustion vs. lithium/water

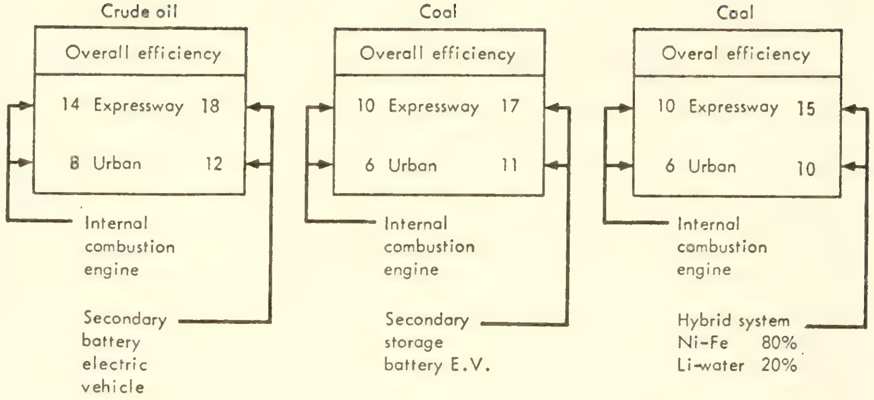


Fig. 9. Overall efficiency comparison of automotive propulsion system.

FEASIBILITY OF THE LITHIUM-WATER SYSTEM AS AN AUTOMOTIVE ENERGY SUPPLY

VEHICULAR SYSTEM OPTIONS

In this section the characteristics of three electric vehicle configurations are examined; the secondary battery powered vehicle, the primary battery powered vehicle, and the battery hybrid vehicle.

Figure 10 shows a simplified block diagram of a secondary (rechargeable) battery powered vehicle. Most existing electric vehicles have this basic configuration. Propulsion energy is obtained by storing utility power in the battery via either an external or onboard battery charger. During vehicle operation, the battery discharges under operator control into the propulsion load consisting of the motor, drive train, and motive accessories. The power controller contains the electrical and electronic circuitry necessary to operate on the driver's commands and transmit the required power from the battery to the propulsion load. Since the propulsion battery is rechargeable, a portion of the vehicle's kinetic energy can be recovered when stopping or slowing through regenerative braking. Under regenerative braking the propulsion motors act as generators and recharge the batteries through the power controller. Regenerative braking can improve the vehicular system efficiency by approximately 10%.(14)

For a given vehicle design and fixed battery weight, vehicle characteristics are determined by battery parameters. As stated earlier, vehicle performance is determined by the battery's power density and range by its energy density. Range extension is made possible either through rapid cell recharge or battery exchange. The operating cost of a secondary battery powered vehicle is determined primarily by the cost of electric utility power. Operating cost is also a function of battery lifteime. Frequent battery replacement can significantly increase it.

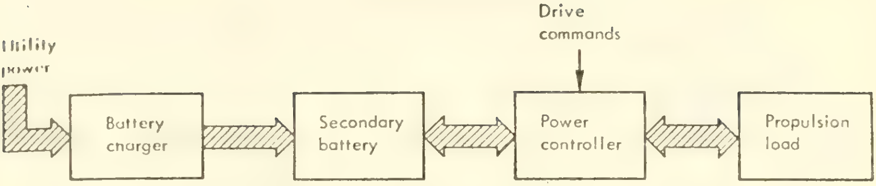


Fig. 10. Secondary battery vehicle

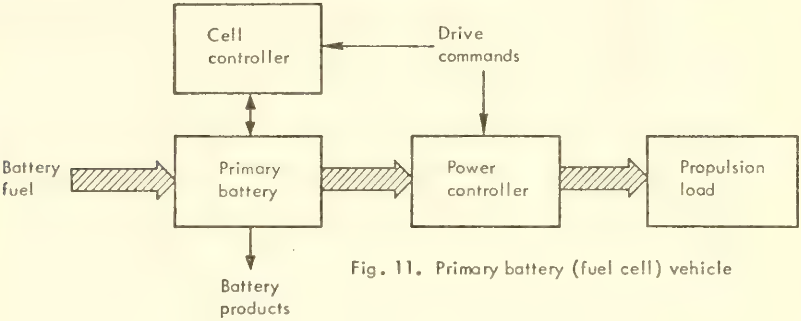


Fig. 11. Primary battery (fuel cell) vehicle

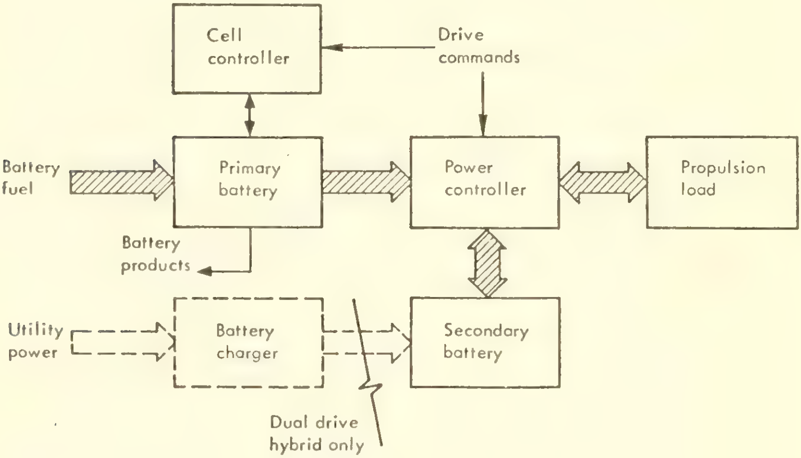


Fig. 12. Battery hybrid - power buffered hybrid or dual-drive hybrid

Figure 11 is a block diagram of a primary (non-rechargeable) battery or fuel cell operated vehicle. Here, propulsion energy is provided by fuel that is converted by chemical action to electrical energy. The primary cell also generates a reaction waste product. For the Lithium-Water battery containing an air cathode, the fuels are lithium, carbon dioxide and oxygen from the air; the battery product is lithium carbonate. A cell controller is shown in Figure 11. The primary battery operation is generally complex enough to require a controller to operate the necessary pumps, valves, timers, and sensors.

Since the primary battery is not rechargeable the primary powered vehicle is incapable of regenerative braking. The power controller is relatively simple since it transmits power in one direction only.

Like the secondary battery vehicle, the performance of the primary powered vehicle is determined by peak battery power. Range, however, is determined by the amount of onboard fuel. Range extension is accomplished either by mechanical recharging (refueling) or by battery exchange. The operating cost of the primary cell vehicle is determined principally by the cost of the battery fuel.

The general configuration of the battery hybrid vehicle is shown in Figure 12. There are two types of battery hybrid vehicles, the power-buffered hybrid and the dual-drive hybrid. These differ only in the size of the secondary battery and the method of vehicle operation.

The power-buffered hybrid is essentially a primary battery powered vehicle. The secondary battery acts as a buffer between the primary battery and the propulsion load. It accepts power when the primary battery output exceeds the required propulsion power, and it supplies propulsion power when the load demands exceed the primary battery power setting. This buffered configuration allows the primary battery to operate near the vehicle's average power consumption level, thus reducing its peak power requirements. In addition the buffer allows the primary battery to change power levels slowly. The present Lithium-Water cell operates much more efficiently with slow power changes. In the power buffered vehicle the secondary battery is sized only large enough to provide or accept energy during primary battery power changes. The vehicle cannot run for more than a few minutes on this secondary battery energy.

The dual drive hybrid vehicle, although having a control configuration identical to the buffered hybrid, contains a larger secondary battery and therefore sufficient energy to operate the vehicle for short trips without the aid of the primary battery. Secondary battery recharge energy is obtained either from utility power or from the primary battery. For normal urban operation, electric utility power would provide the major source of energy, with the primary battery being used only to extend the secondary battery's range. For longer trips the vehicle operates as a power buffered hybrid.

Regenerative braking is possible in both hybrid vehicles by allowing energy to flow from the propulsion motors into the secondary battery during vehicle deceleration. The hybrid power controller is relatively complex. It must be capable of sensing vehicle parameters and translating driver commands into an energy flow along any one of four paths; from the primary cell to either the secondary battery or the propulsion load and in both directions between the secondary battery and the propulsion load.

Differing factors determine operating costs for the two hybrid systems. In the power buffered hybrid, as in the primary battery powered vehicle, operating cost is determined principally by the cost of battery fuel. The operating cost of the dual drive hybrid, on the other hand, lies somewhere between the operating costs of the power buffered hybrid and the much lower costs of the secondary battery vehicle. For short trip urban operation, the dual drive hybrid's operating cost should approximate the secondary battery driven vehicle with costs being determined by the price of utility power and secondary battery lifetime. For both hybrids range extension is by mechanical recharge or primary battery exchange.

Range for a power buffered vehicle is essentially determined by the amount of onboard primary battery fuel. For the dual drive vehicle both the fuel and the stored secondary battery energy determine vehicle range. For both vehicle types, maximum sustained power is the maximum primary battery power, however, power can be drawn for short durations from both the primary and secondary batteries with the maximum vehicle power approaching the sum of battery powers. This power can be sustained much longer in the dual drive vehicle.

REPRESENTATIVE VEHICULAR SYSTEM

As an example of how the Lithium-Water-Air battery adapts to automotive propulsion, we have selected a representative vehicular propulsion system as shown in Figure 13. We have chosen the power buffered hybrid system since it most closely compliments the present Lithium-Water-Air battery characteristics. The representative vehicle was selected as an evaluative exercise only and its parameters shown in Figure 14 do not represent a serious attempt at vehicle design.

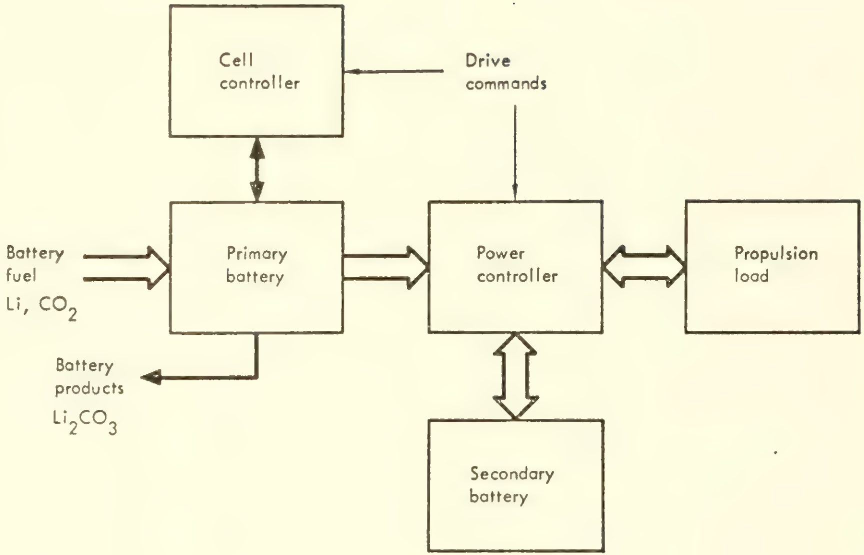


Fig. 13. Representative vehicular propulsion system (power buffered primary battery)

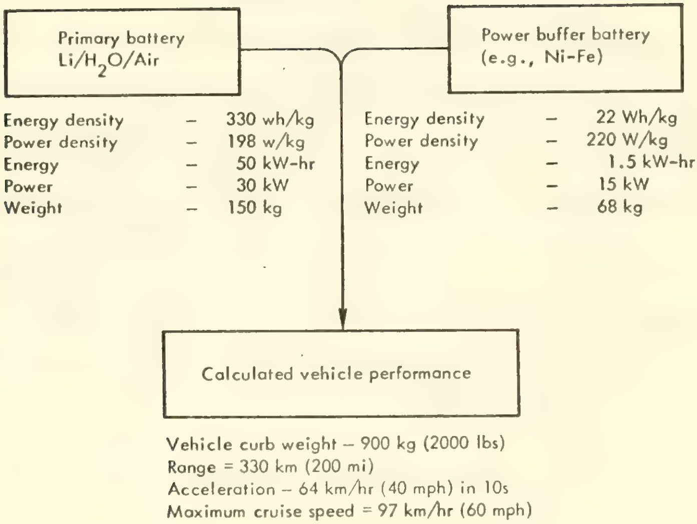


Fig. 14. A primary battery ($Li/H_2O/Air$) combined with a power buffer battery provides a system of acceptable performance.

The representative vehicle weight is loosely based on present-day sub-compact cars with the total battery weight arbitrarily limited to 500 lbs. Estimated energy and power densities were used for the Lithium-Water-Air battery and data based on presently available Nickel-Iron batteries were used for secondary battery parameters. Secondary battery size was chosen to provide peak power for a tenth of an hour. The primary battery is sized to provide a 330 km range (200 mi) at a projected utilization of 155 watts/km (250 watts/mi) and a maximum sustained speed of approximately 97 km/hr (60 mph). An acceleration of greater than 64 km/hr (40 mph) in 10 seconds can be achieved without secondary battery power.

SYSTEM DESIGN EFFECTS

Vehicle Design

The impact of the Lithium-Water buffered primary system on electric vehicle performance is illustrated in Table 3. As a basis for comparison, we have chosen the 1975 Seneca, manufactured by Linear Alpha, Inc. The specifications for this commercially-available electric vehicle are shown in the first column. The specifications are taken from (or estimated from) the company's specification sheet. The second column gives specifications for a vehicle with 330 km range with a Lithium-Water-Air buffered primary system replacing the Pb-Acid batteries. Note that this vehicle is about 30% lighter than the Seneca; its increased acceleration and cruising speed are due to the three-fold improvement in specific power. The purchase price estimates are based solely on the vehicle weights and on the simplifying assumption that mass-produced vehicles will sell at $3.3/kg ($1.5/lb) in 1985.

		Linear Alpha, Inc. 1975 Seneca (Pb-acid batteries)	Representative battery system
Range (km)		97 (60 mi)	330 (200 mi)
Passenger capacity		2	4
Est. veh. wt. (Kg)		1,450	1,000
Est. battery wt. (Kg)		680	220
Battery energy (kw-hr)		23	51
Specific energy (w-hr/Kg veh.)		16	51
Battery power (kw)		23	45
Specific power (w/Kg veh.)		16	45
Normalized acceleration		1	3.0
Cruising speed (KmH)		64 (40 mph)	88-96 (55-60 mph)
Cost ($)	Unit prod (1975)	7,000	–
	Mass prod (1985) (est at 3.3/Kg)	4,800	3,300

Table 3. The representative battery system provides a vastly improved performance capability to a currently available electric vehicle.

It should be pointed out that the comparison to the Seneca was made for reference purposes only and that the vehicle design we envision is in no way tied to that of the Seneca. Indeed, there are many design options for further improvements which deserve further study.

Drive motor options should be investigated. AC motors seem more attractive than DC motors in both specific weight (kg/kw) and specific cost ($/kw). In the past, the AC system has not been frequently used because of its costly, complex and heavy controller. The recent development of high current Darlington transistors coupled with integrated circuit logic elements may represent a very significant technological advance in controller performance for AC systems. This approach, which can also handle regenerative braking requirements, should be investigated. Chassis/body design, including the reduction of weight, rolling and drag losses must also be studied.

Vehicle Refueling and Servicing System

As indicated previously the representative vehicle (900 kg) powered by a Lithium-Water battery will have a range of 330 km (200 mi). This is essentially a primary battery system and recharging would consist of mechanically renewing the lithium anodes recharging the carbon dioxide reservoir, and removing the lithium carbonate. With a range of 330 km the present system of service stations is properly distributed although not presently equipped to provide service.

The refueling process, assuming maximum range travelled would consist of removing 38 kg of lithium carbonate in a slurry form, adding 23 kg of carbon dioxide and 7 kg of lithium. Proper design of the vehicle can lessen the task of refueling. Several concepts can be postulated. The system chosen should require minimal time at the service island. Lengthy refueling times will probably be unacceptable to the public.

One concept is to modularize the battery, particularly those components involved in refueling so that they can be removed easily. The carbon dioxide refueling should be a rather simple matter of recharging tanks. However, this will require equipping the service center to handle high pressure gas. Since the lithium carbonate will be quite heavy, the package can be divided into a number of small modules, or handling equipment will have to be made available. In any case, the waste modules can be returned to reprocessing centers.

Changing the lithium plates will be more tedious. The battery can be designed, however, so that plate modules can be rapidly removed, using quick disconnects. These modules should not be heavy; at replacement they should weigh about 10 kg, so no special handling equipment is required. Rebuilding lithium modules at the service center rather than at some central processing center is a possibility. This can eliminate transporting nonactive module parts. The decision will most likely be dictated by economics. If transportation costs are low enough, rebuilding at a central plant would be more suitable since better quality control and safety standards can be maintained.

Another refueling approach is to design a system with mechanical equipment (e.g. a slurry pump) available to remove the lithium carbonate from the vehicle. In the process it is transferred to a central collection container at the service center for later removal to the reprocessing center.

The carbon dioxide and lithium would be handled as before. The essential difference, therefore, is less handling of the lithium carbonate and a lower total weight is transported to the reprocessing center.

The most tedious refueling task in the above systems is lithium replacement. The lithium range of the vehicle can be extended by adding lithium to the battery. If, instead of 7 kg, the battery carried 35 kg of lithium then the vehicle could travel 1609 km (1000 miles) between lithium changeouts. Assuming the average of 16,000 km/yr (10,000 mi/yr) travel then the lithium need only be refueled every 1.2 months. Lithium refueling would not take place at the "gas" island, but as part of a more lengthy servicing of the E.V., similar to the 1600 km (1000 mi) oil change. Routine refueling would then consist of adding carbon dioxide and removing lithium carbonate.

The refueling of the Lithium-Water-Air battery does not seem to pose any fundamental obstacles. If the range can be extended for lithium, then refueling can approach the ease and speed of that afforded the present-day gasoline vehicle. A more detailed study is required, of course, to determine what is desirable from the vehicle design, service center, and economic standpoint.

The distribution system from the service center to the reprocessing center and return does not exist as such, and will have to be established. This will require a large capital expenditure, and may require some interim steps at first. This requires further study.

We have assumed refueling at 330 km (200 miles), but normally drivers refuel before the maximum range has been reached. The vehicle design must consider this and lithium carbonate is valuable and must be returned in order for this system to be economically feasible.

Since makeup water and carbon dioxide will be obtained from local sources, the effect of impurities on the battery operation must be determined. Water will undoubtedly be the main problem.

Finally attention must be paid to safeguards against "poisoning" the lithium carbonate so that the reprocessing system is not harmed. Since the carbonate has considerable value attempts will be made to "cheat" the system. Considerable thought should be given to finding the best way of providing these safeguards.

ECONOMIC, POLITICAL AND SOCIAL IMPACT

Economics of Lithium-Water-Air Battery Use

In the nominal system wet lithium carbonate is removed from spent primary batteries at service stations. This is illustrated in Figure 15. The lithium carbonate is collected and shipped to regional reprocessing plants where it is converted again into lithium battery anodes. Currently available technology would involve conversion of the carbonate to lithium chloride, followed by electrolysis of the chloride to lithium metal and chlorine. Since a number of different chemical routes can be considered for these steps, a detailed survey of current industrial practices and of possible alternatives will be required to establish the most economical ones.

Initial Inventory Costs - The current cost of new lithium metal produced from ore is $20.64 per kg. On the basis of discussions with lithium and sodium producers, it has been stated that this figure could be reduced to about $4.40/kg ($2/lb) in quantities of 1 million pounds/year

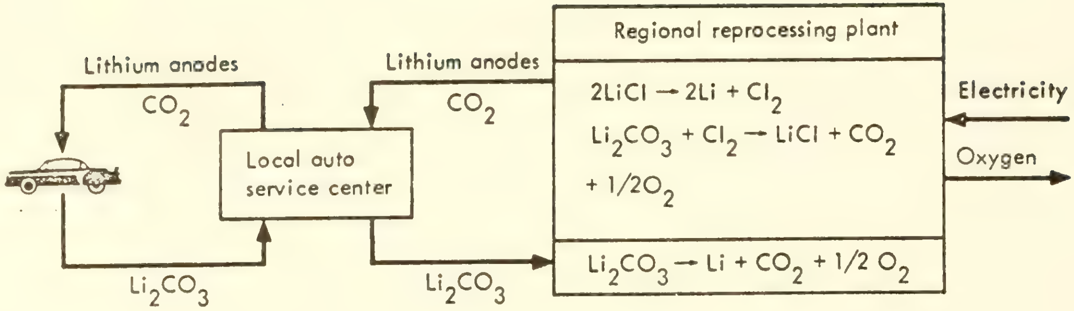

Lithium anodes
CO_2
Li_2CO_3
Local auto service center
Lithium anodes
CO_2
Li_2CO_3
Regional reprocessing plant
$2LiCl \rightarrow 2Li + Cl_2$
$Li_2CO_3 + Cl_2 \rightarrow LiCl + CO_2 + 1/2O_2$
$Li_2CO_3 \rightarrow Li + CO_2 + 1/2\ O_2$
Electricity
Oxygen

Fig. 15. An automotive system involves recycling of Li_2CO_3 to a reprocessing plant.

or more.(16) This figure thus would represent a lithium capital inventory cost of $32 per auto. In addition, it is assumed that an additional inventory of lithium equal to this amount would be in process through the recycle system.

Charge Cycle Costs - There is considerable uncertainty about the cost of reprocessing lithium carbonate to lithium metal. Foote Mineral(16) has stated that for quantities greater than 1 million pounds/year, and starting with lithium carbonate, the cost of preparing metal would be in the range of $2.2/kg. Costs of $1-2 per kg will be required for the Lithium-Water-Air system to be competitive; thus considerable improvement over the Foote estimate will be needed. It should be noted that the current lithium industry is relatively small; U.S. production is only about 4-5 thousand metric tons/year. Two other metals produced in large quantities by electroytic methods are sodium and aluminum. Lithium probably could be produced in currently existing sodium facilities. The price of sodium is about 40¢/kg and the price of aluminum is 65-85¢/kg. On the basis of relative atomic weights, lithium should be about three times as expensive as sodium, or about $1.20/kg. The setup of very large production facilities would be needed to make this price realistic. However, a recycle cost for lithium of about $1.50/kg does not seem unreasonable.

Although lithium is a reactive metal, with proper care and facilities it is not difficult to handle in a dry atmosphere. It is extremely soft and can easily be shaped. Therefore, fabrication into anode assemblies should not be difficult or expensive.

Very little can be said at present about the costs of air cathodes. Possible materials could be porous carbon or Teflon, impregnated with small amounts of activator, such as silver or other metals. Overall materials costs should be low.

Other battery and battery system components appear to be straightforward in fabrication technology and cost. Such items as tanks, pumps, molded plastic battery containers and filters are familiar to the auto industry and would appear to present no special cost problems.

Carbon dioxide will also have to be supplied at service stations. The current cost of CO_2 is about 44¢ kg, supplied in standard 2 cu ft pressure cylinders. In large quantities, this cost can be reduced to 22¢/kg or less;(17) in the quantities needed for an automotive industry, this cost probably can be cut in half. The nominal auto starting with a fresh charge of 7.3 kg of Li will require 23 kg of CO_2.

Discharge Cycle Costs -- The principal costs associated with the discharge cycle are: 1) transportation of the lithium anode assemblies and CO_2 containers from the regional processing plant to the service station network; 2) handling charges for installing new assemblies and supplies in automobiles and removal of Li_2CO_3 slurry; and 3) collection and transportation of Li_2CO_3 slurry and spent anode containers to the regional processing plants.

Typical transportation costs for packaged items such as batteries or CO_2 cylinders is about 13¢/ton km.(17) Assuming an average delivery trip length of 25 km (40 mi) the average transportation cost for these items would be .005¢/kg for the lithium; .015¢/kg Li for the CO_2; and .025¢/kg for the Li_2CO_3.

Typical handling costs at the service station should be analogous to current handling costs of about 2¢/kg of material. For the lithium metal and lithium carbonate handling, this amounts to about 12¢/kg of Li. Costs for handling water and CO_2 are assumed to be negligible.

The operating cost per mile of an automobile powered by a Lithium-Water-Air battery is highly dependent on the cost of lithium reprocessing. Figure 16 puts these costs in perspective. Assume a cost of 1.50/kg for lithium, the representive vehicle denoted by the primary curve would have an operating cost of 7.4¢/mi. Today's vehicle with a 20 mpg range costs 3¢/mi before tax to operate.* A battery/battery hybrid, e.g. with a 20 mi range secondary, would have an operating cost of about 3¢/mi. An appropriately designed Lithium-Water-Air battery automobile thus can have a competitive operating cost. Considering possible future increases in gasoline price, comparisons are indeed favorable. Although these cost estimates are very crude, they indicate that the technical possibilities offered by the Lithium-Water system must be investigated.

Future Inventory of Lithium

Some estimate of the amount of lithium required can be had using the following:

Lithium consumption: 7.3 kg (16 lb)

Automobile range: 330 km (200 mi)

Number of electric cars:

Year 1985	0.2-1 x 10^6 (14,19)
Year 2000	18-25 x 10^6 (14,19)

For every battery in use, an additional battery will be in process of recharge. Thus for each electric automobile in use, 14.6 kg (32 lb) of lithium is needed. Aquisition of more exact data may cause this estimate to change in the future so a range of 13-17 kg (29-37 lbs) per electric vehicle is probably a better statement of the requirement.

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[*] This accounts for gasoline only.

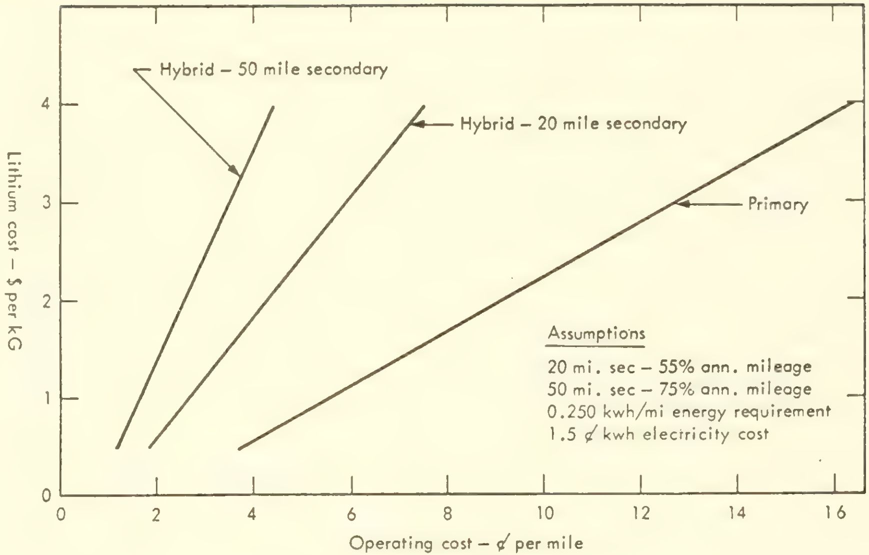

Fig. 16. Vehicle operating costs are a function of system design.

Taking all lithium/H_2O powered vehicles into account:

Year	No. Electric Vehicles	Lithium Required (metric tons)
1985	$0.2\text{-}1 \times 10^6$	2,600-17,000
2000	$18\text{-}25 \times 10^6$	234,000-425,000

Lithium Resources - Lithium heretofore has had a limited number of uses, and the domestic industry has not been aggressive in expanding the U.S. reserves. Table 4 contains a resume of current estimates of reserves and resources.

Reserves	Metric Tons
Kings Mtn., N.C.	441,000
Searles Lake, Ca.	9,100
Silver Peak, Nev.	45,300
TOTAL	495,400
Identified-Subeconomic Resources	
Geothermal Brine, Niland, Ca.	998,200
Great Salt Lake, Utah	698,800**
TOTAL	1,697,000

Table 4. Lithium Reserves and Resources*

*Estimates February 14, 1975, J. D. Vine USGS, Denver.

**Assumes all water in the lake is utilized. Gulf Resources and Chemical Corporation's venture to extract this lithium was recently reported as having been abandoned.(26)

It is noteworthy that these latest estimates are below those made within the last two years by the Bureau of Mines(20) and the U. S. Geological Survey.(21) The largest reserves in the U.S. are in the form of the mineral spodumene ($LiAlSi_2O_6$) which is mined in North Carolina, as noted in Table 4. The world supply of lithium is imperfectly known primarily because exploration has not been intensive. The unexploited world resource has been estimated at 10-11 million tons.(20,21) It resides chiefly in Rhodesia, Canada, and S.W. Africa.

Domestic Lithium Production - The U.S. production and consumption data are not accurately known primarily because of the few companies in the field and the resulting proprietary nature of the information. Some information can be gleaned from company financial reports which indicate that the total 1974 production capacity was 4500 tons of lithium.(25) Assuming that the plants run at 70-90% capacity, the current annual production is on the order of 3600-4500 metric tons annually. This is up from the 1970 total production capacity of 1700 metric tons. These estimates are given in Table 5 together with cumulative estimates through the year 2000. An 8% increase in production per year has been assumed.*

Year	(Metric Tons) Annual Production	(Metric Tons) Cumulative Production
1970	3,000	
1974	4,500	
1985	10,900	80,000
2000	36,300	400,000

Table 5. U.S. Lithium Production

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*The U.S. annual growth rate since 1968 is estimated to have been 10%.(22)

These numbers may be considered to be on the high side since they assume a constant and high growth rate (8%) over the period and take no account of possible conservation and recycling of used lithium in any industry.

Adequacy of Supply - A comparison of the estimated amount of lithium to be produced and consumed in the U.S. in the year 2000 by conventional technologies (fluxes, in aluminum industry, in greases, etc.) with the current reserves and resources (Table 6) indicates that the lithium reserves will have to be expanded to accommodate the demand. Extensive use of lithium batteries is not possible without expansion of the domestic supply of lithium.

Reserves:	495×10^3
Identified-Subeconomic Resources:	$1,697 \times 10^3$
Cumulative Demand:	
Customary uses (glass, ceramics, aluminum, fluxes, greases, etc.)	$318\text{-}400 \times 10^3$
Li/H_2O Batteries ($18\text{-}25 \times 10^6$ vehicles):	$234\text{-}425 \times 10^3$

Table 6. Estimates of U.S. Supply and Possible Demand For Lithium to the Year 2000 (Metric Tons)

Because a lithium-battery industry is likely to develop in incremental steps, there appears to be adequate lead time to develop the "identified but currently subeconomic resources" of the Salton Sea brine and the Great Salt Lake as well as to drill and explore elsewhere for lithium-bearing pegmatites or brines. Once the demand is established, it is likely that the U.S. lithium industry as well as the U.S. Geological Survey's Exploration Groups will be able to locate new resources.

Electric Power Industry Impact

The representative vehicle is for all practical purposes a primary battery-powered E.V. Electricity would therefore be required primarily to reprocess lithium. A vehicle can also be configured as a battery/battery hybrid. In this case, electricity will be needed to reprocess lithium in lesser amounts and primarily used to recharge secondary batteries at night and during off peak load periods. Table 7 repeats expected introduction rates of E.V.s.

	1985	1990	2000
EPRI EST.(9)	1×10^6	5×10^6	25×10^6
ANL EST.(28)	0.2×10^6	1.8×10^6	18×10^6

Table 7. Estimated Electric Vehicle Population

The effect on the electric power industry is design-dependent, and Table 8 gives an indication of such effect. Using the high E.V. introduction rate from Table 7, the representative vehicle, and the estimated growth rate of the U.S. electric power generating capacity,(27) the E.V. introduction assumed will have minimal effect. In fact it will probably be beneficial in that some of the energy can be expended during off-peak periods.

	1985	1990	2000
High E.V. population	1×10^6	5×10^6	25×10^6
Li reprocessed kg/yr(11)	0.37×10^9	1.94×10^9	9.2×10^9
Electric power KWH/yr req'd for reprocessing	10×10^9	54×10^9	257×10^9
Est. U.S. electric power generating capacity KWH/yr(28)	8.5×10^{12}	11×10^{12}	16.7×10^{12}
Percent generating capacity req'd for E.V.	0.1	0.5	1.5

Assumptions: E.V. utilization--16,000 km/yr (10,000 mi/yr)
E.V. fuel consumption--44 km/kg Li
(0.023 kg Li/km)
Electric energy for Li reprocessing--28 KWH/kg(1)

Table 8. E.V. Impact on Electric Power Industry

The impact of increasing the introduction rate should be examined.

Automobile Industry Impact

It seems clear that the introduction of E.V.'s will be gradual. Table 9 indicates a modest increase in the percentage of E.V.'s to total automobiles. Again the high E.V. introduction rate was assumed. By the year 2000 it is expected that 16.5% of all automobiles will be E.V.'s.

	1975	1985	1990	2000
Auto Population(28)	92×10^6	126×10^6	134×10^6	151×10^6
Assume high E.V. population	0	1×10^6	5×10^6	25×10^6
E.V. Percent	0	0.8	3.7	16.5

Table 9. Projected E.V. Impact on the Automotive Industry

Many of the design requirements important to electric vehicles are already becoming of prime concern to the automotive industry in its effort to increase fuel economy--light weight, low rolling resistance, and low aerodynamic drag--so these will not be new. However, mass producing batteries of the energy and power density required is a problem that must be addressed. Design studies must consider this, and also establish chemical and mechanical tolerances commensurate with low cost of manufacture. Electric motors are relatively expensive and long-lasting. Lower cost is mandatory; the motor life must equate with vehicle life. This requires further design study. Electronic controls must be developed that are reliable and also have minimal cost. In view of the present expansion state of the electronics industry, this should not be difficult to achieve.

Electric vehicles will be quite different in concept from the present internal combustion engine vehicle and thus will require different servicing. Therefore new servicing equipment will be required and service personnel will require retraining. The automotive aftermarket (the replacement parts industry) will include a host of new components. However, because of the gradual nature of the E.V. introduction, these changes should have a minimal effect on the industry.

Impact on Private Transportation

The effect of the Lithium-Water-Air battery E.V. on the private transportation sector is most certainly design-dependent. The representative vehicle would have a performance which should be compatible with present traffic conditions, both urban and expressway-type traffic. A credible acceleration is postulated, greater than 64 km/hr (40 mph) in

10 sec, and the sustained top speed of greater than 97 km/hr (60 mph) is in excess of the present national speed limit.

Therefore, the representative system, if designed for extended lithium range, is expected to have a minimal effect on private transportation. However, unless the cost of lithium reprocessing can be reduced, the operating costs will be high. This, of course, will lessen the attraction of the vehicle. Servicing will be more frequent and the driver will notice a quieter ride.

The hybrid system will reduce the average operating cost to a level that is competitive with the present ICE vehicle. Service center refueling will be extended past the 330 km range, but the driver will be required to plug his vehicle into a recharge unit when it is not in use, to insure an adequate charge level at all times in the secondary battery.

The effect of this E.V. on the driving public, therefore, is quite design-dependent. Design studies are required to insure that the vehicle is maximized for performance at minimal cost.

Environmental Impact

While no extensive environmental analysis has been made of this vehicle, it appears that the operation will be environmentally clean. Recharge energy and/or reprocessing of lithium can be generated or accomplished outside the urban basins and can be more readily controlled to insure a clean operation. Thus from an operation standpoint this E.V. should be an environmental improvement. A further detailed study is, of course, required.

There are some associated unknowns that must be investigated; the effect of extensive lithium mining, large scale lithium reprocessing, and new forms of chemical spills. With proper design foresight these are not expected to cause serious problems.

Oil Import and Balance of Trade

The effect upon oil imports and the resultant balance of trade will depend, of course, on the introduction rate of these E.V.'s. Table 10 indicates that the annual savings of oil will be minimal (2.4-12 x 10^6 bbls/yr) in 1985 when E.V.'s are expected to first have a noticeable effect. This should steadily increase thereafter until by the year 2000 oil savings should be between 225 x 10^6 and 300 x 10^6 bbls per year. This is approaching 1 x 10^6 bbl per day. The U.S. balance of trade can thus be improved by as much as $12.5 billion.

It is therefore apparent that E.V.'s can have an ever-increasing beneficial effect on the U.S. balance of trade. From the petroleum viewpoint, a more energetic introduction rate might be warranted. However, this will be affected by and affect many other areas of the society and economy. A more detailed study of what might constitute a reasonably accelerated E.V. growth rate, the effects on society, and what might be done to bring it about, is necessary.

		1985	1990	2000
E.V. Population	HI(14)	1×10^6	5×10^6	25×10^6
	LO(19)	$.2 \times 10^6$	1.8×10^6	18×10^6
Est. Annual Oil Savings (bbl) (Coal/Nuclear Power for Reprocessing only)	HI	12×10^6	60×10^6	300×10^6
	LO	2.4×10^6	22×10^6	225×10^6
Est. Annual Oil Import Savings ($) (Coal/Nuclear Power for Reprocessing only)	HI	132×10^6	660×10^6	3.3×10^9
	LO	30×10^6	240×10^6	12.5×10^9

Assumptions: Auto utilization - 16,000 km/yr (10,000 mi/yr).
Gasoline fuel consumption - 8.5 km/ℓ (20 mpg).
Conversion factor - 159 liters/bbl (42 gal/bbl).
Oil price - $11/bbl.

Table 10. E.V. Impact on Oil Imports

REFERENCES

1. C.J. Anderson, et. al., *An Assesssment of U.S. Energy Options for Project Independence*, Lawrence Livermore Laboratory, Rept. UCRL-51638,(Sept. 1, 1974).

2. "Statistics of Energy 1958-1972", *Basic Statistics*, OECD, Paris, (1974).

3. J.J. Mutch, "Transportation Energy Use in the United States. A Statistical History, 1955-1971", prepared for the National Science Foundation by Rand Corp., R-1391-NSF (December 1963).

4. H.J. Halberstadt, "The Lockheed Power Cell", Lockheed Missile & Space Co., SAE Paper No. 739008.

5. D.V. Ragone, "Review of Battery Systems for Electrically Powered Vehicles", SAE Paper No. 680453, SAE mid-year meeting, Detroit Mich (May 1968).

6. J.E. Winn, "Low Cost Oxygen Electrodes", Research and Development Technical Report ECOM-3354 (1970).

7. K. Otto, "A Thermal Battery Based on the Reaction of Cadmium and Liquid Iodine", *J. Electrochem Soc*. (111),1317 (1964).

8. W.K. Behl, et. al., "Lithium Inorganic Electrolyte Cells Utilizing Solvent Reduction", *J. Electrochem Soc*. (120),1619 (1973).

9. J.J. Auborn, et. al., "Lithium Anode Cells Operating at Room Temperatures in Inorganic Electroytic Solutions", *J. Electrochem Soc*. (120),1613 (1973).

10. W.J. Ramsey, Lawrence Livermore Laboratory, private communication (March 1975).

11. R. Bauer, "Lithium from the Standpoint of Electrochemistry", *Chemie-Ingenieur Technik*, 44:4, 145-151 (1972).

12. G.T. Motock, "Electrolysis of Lithium Chloride in the 1000 Ampere Cell", *Electrochemical Technology*, (March-April 1963).

13. Charles Mantell, *Engineering Electrochemistry*, (McGraw Hill, New York, 1960).

14. F. Kalhammer, "Energy Storage Incentives and Prospects for its Development", *Amer. Chem. Soc*. (September 12, 1974).

15. George H. Gelb, et. al., "Performance Analysis of Heat Engine-Battery Hybrid Vehicles", *Proceedings of the 7th Intersociety Energy Conversion Engineering Conference, 1974*, paper #729144, p. 987.

16. Foote Mineral Co., private communication (March 1975).

17. Matheson Chemical Co., private communication (March 1975).

18. Lockheed Missile & Space Co., private communication (March 1975).

19. P.A. Nelson, A.A. Chilenskas, and R.K. Steunenberg, "The Need for Development of High Energy Batteries for Electric Automobiles", Rept. ANL-8075 (DRAFT), (January 1974).

20. Commodity Data Summaries, Bureau of Mines, (January 1975), p. 93.

21. J.J. Norton, "Lithium, Cesium and Rubidium -- the Rare Alkali Metals", U.S.G.S. Professional Paper 820, (1973), p. 372.

22. J.D. Vine, U.S.G.S., private communication (Feb. 14, 1974).

23. J. Holdren, "Adequacy of Lithium Supplies as a Fusion Energy Source", LLL, Rept. UCID-15953, (Dec. 8, 1971).

24. "Fusion Power -- An Assessment of Ultimate Potential", WASH-1239, (Feb. 1973).

25. H.B. Wood, U.S. Bureau of Mines, private communication, (Feb. 20, 1975).

26. W.F. Lukenbach, "Lithium -- Burgeoning Demand will Require New Production", Engineering and Mining Journal, (March 1974), p. 96-97.

27. IEEE Spectrum (June 1972).

28. D.G. Harvey & W.R. Menchen, The Automobile -- Energy and the Environment, Hittman Assoc. Inc., (March 1974).

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CHARLES R CARLISLE
VICE PRESIDENT
202 331 7757

July 16, 1975

The Honorable Mike McCormack
United States House of Representatives
Longworth House Office Building
Washington, D. C.

Dear Mr. Chairman:

We understand that your Subcommittee on Energy Research, Development and Demonstration will begin mark-up today of H.R. 5470, the "Electric Vehicle Research, Development and Demonstration Act of 1975." We strongly endorse this bill but do have one suggestion regarding the introduction of demonstration vehicles. I would like to bring this suggestion to your attention before mark-up begins.

St. Joe Minerals is one of the largest producers of lead and zinc ores and metals in the world. In addition, a St. Joe subsidiary, the Energy Research Corporation, has been doing research on nickel-zinc batteries since 1970, research supported mainly by our company but to some extent by U. S. Government agencies.

We share your desire to accelerate the commercial use of electric vehicles and acknowledge the need to spur both the Government and private enterprise in that direction. We suggest, however, that Section 7(a) (1) of H.R. 5470, by requiring the production of approximately 5,000 electric vehicles within a year of enactment, might have the unintended effect of dampening public enthusiasm for, and acceptance of, electric vehicles.

It appears that if electric vehicles are produced in significant quantity within the next year or so they are likely to use lead-acid batteries, be quite heavy (say 6,000 pounds, of which 4,000 would be the batteries' weight) and in typical use have a very limited range and top speed (say, 30-35 miles range and 45 miles per hour). Demonstration vehicles having such characteristics might not find favor, we believe, with most potential commercial and individual users. (We do recognize the value of vehicles now in production to such specialized users as the Postal Service, and our company, through the Lead Industries Association, has supported that project.)

St. Joe would welcome the development of a greatly improved lead-acid battery and probably would gain commercially from such a development. Our own research, however, causes us to believe that the technological break-through which will lead to widespread use of electric vehicles will come through improved nickel-zinc, not lead-acid, batteries.

A really improved nickel-zinc battery can come soon, especially with the stimulus that the enactment of H.R. 5470 would provide. But we do not think it can come within the next year, regardless of the research effort made. Two to three years probably are required.

What, then, do we propose? Very simply, we suggest the amendment of Section 7(a) to read:

> "The Administrator shall enter into such contracts as may be necessary and appropriate for the production, within three years after the date of the enactment of this Act, of significant numbers of urban passenger and commercial vehicles (meeting the standards and criteria developed under subsection (b)) which are specifically designed for electric propulsion as the primary power source."

A combining, along these lines, of the present subparagraphs (1) and (2) would allow Government and the private sector more time to make the initial introduction of demonstration vehicles. It would not, however, change the three-year objective now set forth in H.R. 5470. And, if our judgment about the future of the lead-acid battery is wrong, more time also would be available to do further research on that battery. As we see it, little would be lost and the chances of success significantly increased.

We realize, of course, that views will differ on this important subject. Whether our suggestion is accepted or rejected, we wish you continuing success with the electric vehicle bill, and we shall be glad to give you any help and information we can.

With very best wishes,

Yours sincerely,

Charles R. Carlisle

CRC:dcc

INTERNATIONAL LEAD ZINC RESEARCH ORGANIZATION, INC.

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CABLE ADDRESS NYILZRO NEW YORK
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June 4, 1975

Honorable Mike McCormack
Chairman
Subcommittee on Energy Research,
Development and Demonstration
Committee on Science and Technology
U.S. House of Representatives
Suite 2321
Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. McCormack:

We understand that you are inviting testimony for presentation to the Subcommittee, relative to the Electric Vehicle Research, Development and Demonstration Act of 1975 (H.R. 5470).

We are a non-profit making organization directing research and development for an international group of companies made up of miners and smelters producing lead and zinc.

In this connection, we are seeking to improve lead-acid batteries and to develop zinc-containing batteries for on-the-road vehicle propulsion. We have seen it as essential to use a systems approach to the problem and this has resulted in our joining with General Electric Company in cosponsoring, over the past several years, the production of four preproduction prototype electric multi-stop delivery vans. These are now undergoing refinement and modification to improve their performance.

We are also sponsoring two scientist-engineers to work in collaboration with the Naval Research Laboratory, which has an excellent capability in regard to lead acid battery research, and with Mobile Equipment Research and Development Center (Fort Belvoir) who have expertise in vehicle design. Our objective here is to achieve improved performance from a lead acid battery powered vehicle.

Thus, we feel qualified to offer guidance to the Subcommittee in relation to development of electric vehicles.

Our studies show that the lead-acid battery must be seen as the sole economic power source for on-the-road electric vehicles for at least ten years, and probably for a very much longer period.

"Low temperature" aqueous electrolyte batteries may be developed which might change this view but we believe it to be unlikely, with the possible exception of the Ni-Zinc battery for which a cost penalty would be exacted, due to the high cost of nickel and the relatively high cost of production.

While the range and speed of lead-acid battery powered vehicles are limited, studies have shown that there exists a substantial market for vehicles designed to take advantage of the present state of the art. Details of these studies can be made available to the committee. As an example, one such study led to the estimate that in 1975 demand in the U.S.A. for a vehicle capable of 40 mph and a range of 40 miles would total 326,000 vehicles. Such an electric vehicle would be well within the present state of the art, and of course improved performance would open up a larger potential market.

Unfortunately, the vital components of the electric vehicle are not now available in a design which takes account of up-to-date technology. For example, there is no lead-acid battery, available today, which has been specifically and effectively designed for on-the-road vehicle propulsion. The individual battery companies are not prepared to make the necessary investment, because suitable vehicles are not available and they cannot depend upon there being an adequate market for them to assume the financial risks involved. We have discussed this with battery manufacturers over the years and as recently as May 27th, and this impasse continues.

As regards electric motors, these are available in numerous designs. However, we have not been able to find a suitable electric motor which has been designed for greatest efficiency. This important characteristic of electric motors has traditionally been sacrificed in favor of lower costs; yet, because of the problem of storing sufficient energy in the battery, efficiency of the motor is extremely important to the success of the electric vehicle.

Here again, there is little incentive to the motor manufacturers to carry out the necessary research and development to improve their product.

The situation as regards controls is quite similar.

The range of a typical, economical, electric vehicle might be, say, 50 miles. Much energy is dissipated in braking and this energy cannot be economically recuperated electrically at the present state of technology.

Flywheel technology has advanced to a stage where we calculate that the range of a typical vehicle could be doubled to, say, 100 miles by using a flywheel to store the energy normally dissipated in braking. This energy would be used for acceleration and would provide the additional benefit of reducing the peak power demand on the battery and thus improving its overall efficiency and increasing its life. (The total capacity of any battery falls dramatically when it must supply current at a high rate).

ILZRO has endeavored to promote research and development on a flywheel battery hybrid. Unfortunately, our funds are limited and we must rely upon establishing a cooperative program. To date, in spite of the obvious benefits, we have not been able to persuade a battery company to share the risk involved.

There can be no doubt that electric vehicles can substantially reduce air pollution when operated in cities.

Hon. Mike McCormack June 4, 1975

Our investigations have demonstrated that they can operate at lower cost as compared to gasoline powered vehicles for the missions for which they are designed. Electric vehicles have an attribute which is not always recognized. In order to operate efficiently, power stations (especially those depending on nuclear energy) must operate at a reasonably constant load. Since electric vehicles batteries are charged overnight, in the majority of territories they can be seen as load levelling devices.

Incremental improvements, available from the maximum use of today's technology, in relation to vehicle design, batteries, motors and controls, would considerably extend the usefulness of electric on-the-road vehicles and would ensure that the advanced batteries which may be available in 15-25 years time can be immediately placed in vehicles of advanced design.

Yet, the development of electric vehicles has been frustrated over the past five years by the inability of private industry to assume the risks involved.

Passage of the Electric Vehicle Research, Development and Demonstraction Act (H.R. 5470) would provide the necessary incentives and would, we believe, result in an early and dramatic improvement in all the vital components involved. It would result in a vehicle of very substantially increased capability as compared with the best available today and one which could compete against gasoline powered vehicles simply on the basis of cost and effectiveness.

We therefore urge the passage of H.R. 5470 and stand ready to supply to you any of our data which might help toward this end.

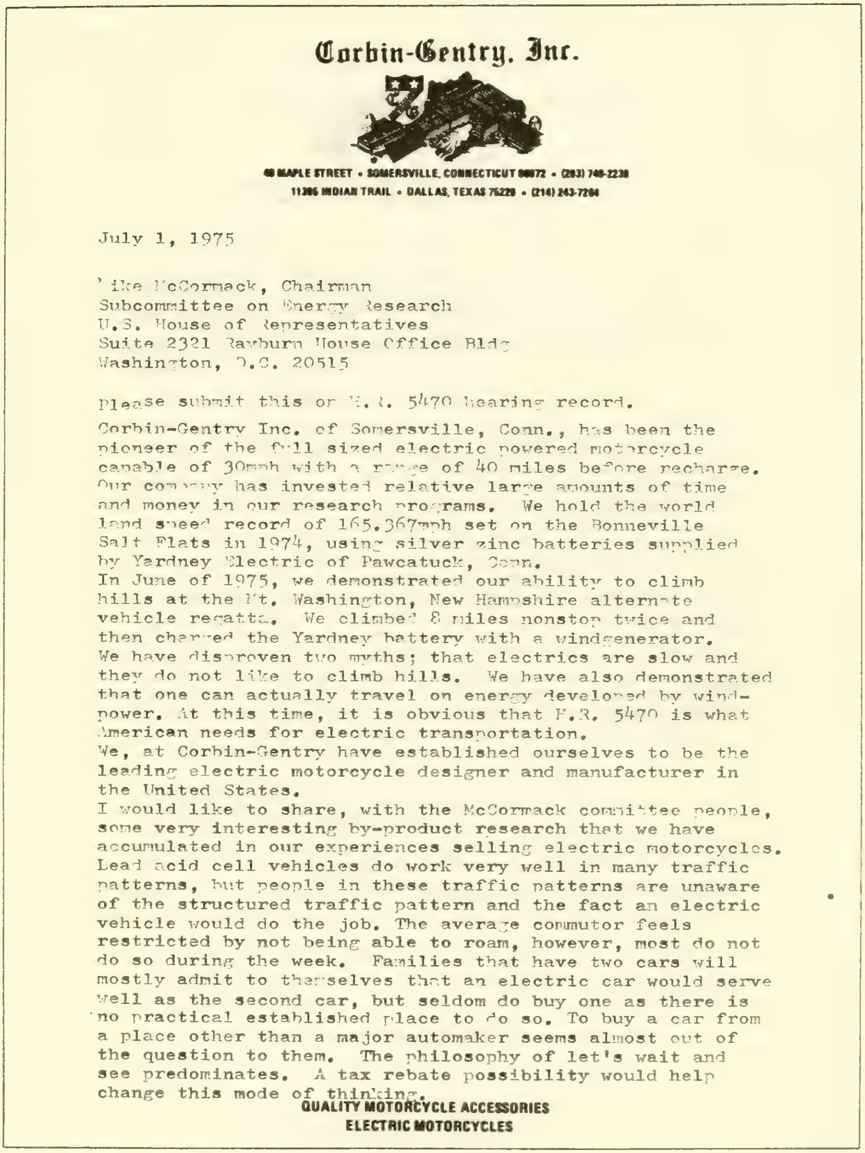
Yours sincerely,

AR Cook.

Albert R. Cook
Manager, Electrochemistry

as

cc: Dr. James M. Lafferty
Mr. Warren Mang
Dr. L. A. Currie



Corbin-Gentry, Inc.

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July 1, 1975

Mike McCormack, Chairman
Subcommittee on Energy Research
U.S. House of Representatives
Suite 2321 Rayburn House Office Bldg
Washington, D.C. 20515

Please submit this on H.R. 5470 hearing record.

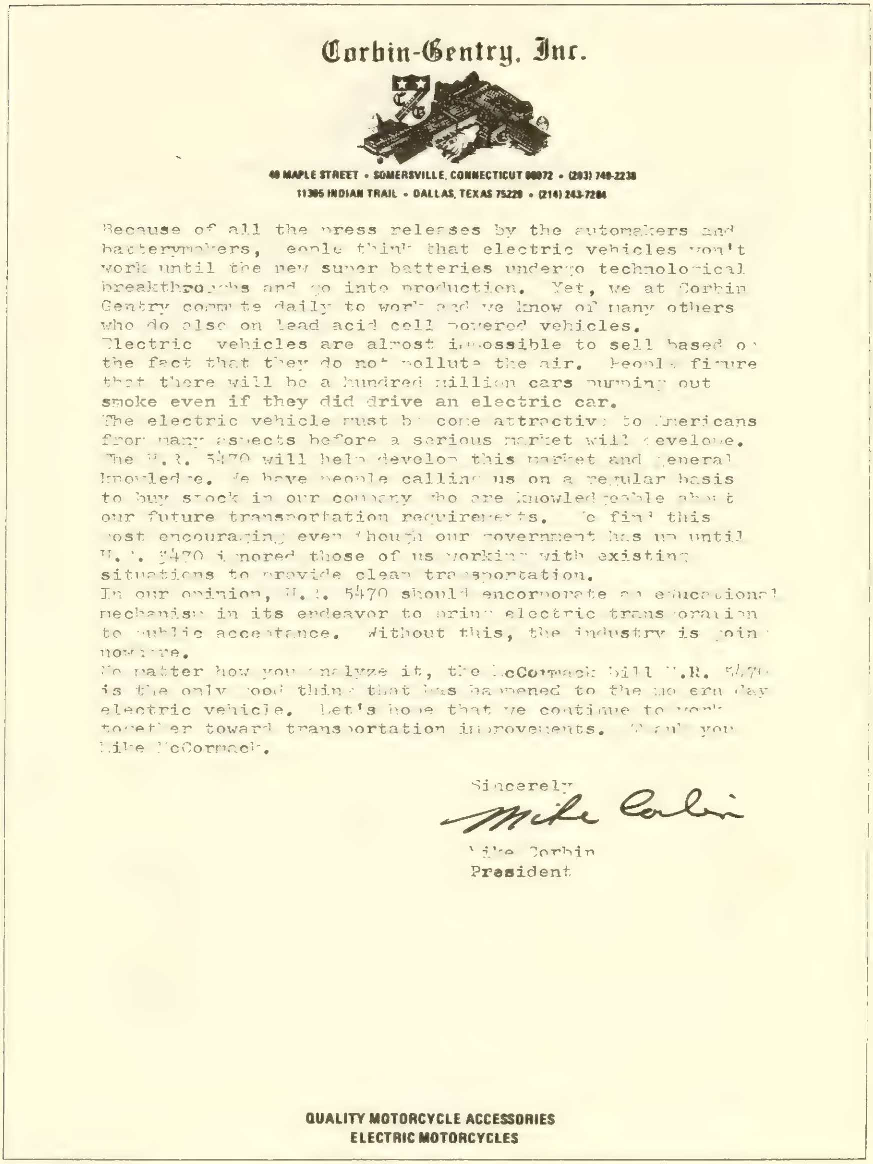
Corbin-Gentry Inc. of Somersville, Conn., has been the pioneer of the full sized electric powered motorcycle capable of 30mph with a range of 40 miles before recharge. Our company has invested relative large amounts of time and money in our research programs. We hold the world land speed record of 165.367mph set on the Bonneville Salt Flats in 1974, using silver zinc batteries supplied by Yardney Electric of Pawcatuck, Conn.

In June of 1975, we demonstrated our ability to climb hills at the Mt. Washington, New Hampshire alternate vehicle regatta. We climbed 8 miles nonstop twice and then charged the Yardney battery with a windgenerator.

We have disproven two myths; that electrics are slow and they do not like to climb hills. We have also demonstrated that one can actually travel on energy developed by wind-power. At this time, it is obvious that H.R. 5470 is what American needs for electric transportation.

We, at Corbin-Gentry have established ourselves to be the leading electric motorcycle designer and manufacturer in the United States.

I would like to share, with the McCormack committee people, some very interesting by-product research that we have accumulated in our experiences selling electric motorcycles. Lead acid cell vehicles do work very well in many traffic patterns, but people in these traffic patterns are unaware of the structured traffic pattern and the fact an electric vehicle would do the job. The average commutor feels restricted by not being able to roam, however, most do not do so during the week. Families that have two cars will mostly admit to themselves that an electric car would serve well as the second car, but seldom do buy one as there is no practical established place to do so. To buy a car from a place other than a major automaker seems almost out of the question to them. The philosophy of let's wait and see predominates. A tax rebate possibility would help change this mode of thinking.



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Because of all the press releases by the automakers and batterymakers, people think that electric vehicles won't work until the new super batteries undergo technological breakthroughs and go into production. Yet, we at Corbin Gentry commute daily to work and we know of many others who do also on lead acid cell powered vehicles.

Electric vehicles are almost impossible to sell based on the fact that they do not pollute the air. People figure that there will be a hundred million cars pumping out smoke even if they did drive an electric car.

The electric vehicle must become attractive to Americans from many aspects before a serious market will develope. The H.R. 5470 will help develop this market and general knowledge. We have people calling us on a regular basis to buy stock in our company who are knowledgeable about our future transportation requirements. We find this most encouraging even though our government has up until H.R. 5470 ignored those of us working with existing situations to provide clean transportation.

In our opinion, H.R. 5470 should encorporate an educational mechanism in its endeavor to bring electric transportation to public acceptance. Without this, the industry is going nowhere.

No matter how you analyze it, the McCormack bill H.R. 5470 is the only good thing that has happened to the modern day electric vehicle. Let's hope that we continue to work together toward transportation improvements. Thank you Mike McCormack.

Sincerely

Mike Corbin

Mike Corbin
President

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June 9, 1975

The Honorable Mike McCormack
Chairman
Subcommittee on Energy Research, Development
and Demonstration
B 374 Rayburn House Office Building
Washington, D. C. 20515

Dear Mr. ~~Chairman~~ Mike:

Recent hearings held by your Subcommittee on advanced automobile research and development are most welcomed. Serious Congressional consideration to promote Federal direction and commitment to conserve energy and control air pollution is essential.

Alternatives to combustion engines must be found to provide American consumers with energy efficient, low polluting automobiles. Advances have been made with the electric car, Stirling cycle engine, and Rankine cycle engine, but further development and demonstration are needed. Based on my strong conviction that legislation is necessary to prod these efforts, I introduced a bill designed to stimulate the search for the production within 4 years of a prototype automobile. The research and development of such a prototype would be conducted under the auspices of E.R.D.A.

Since the content of H.R. 6354 is closely related to the proceedings conducted by your Subcommittee last week, I respectfully urge your consideration of the Automotive Transport Research and Development Act of 1975 during the mark-up session on H. R. 5470, the Electric Vehicle Research and Development Act of 1975. A copy of the bill is enclosed for your information.

Development of an advanced automobile to meet the needs of smog choked cities and the needs of consumers and the

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nation for fuel efficiency is mandatory. It is my sincere hope that you will review H. R. 6354 and Incorporate it into related legislation before your Subcommittee.

Thank you for your kind consideration of this request.

With kindest regards,

Sincerely,

JAMES C. CORMAN
Member of Congress

JCC:mo

94th CONGRESS
1st Session

H. R. 6354

IN THE HOUSE OF REPRESENTATIVES

April 24, 1975

Mr. Corman introduced the following bill; which was referred to the Committee on Science and Technology

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A BILL

To establish a research and development program leading to advanced automobile prototypes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Automotive Transport Research and Development Act of 1975".

Sec. 102. The Motor Vehicle Information and Cost Savings Act (15 U.S.C. 1801 et seq.) is amended by adding at the end thereof the following new title:

"TITLE V—RESEARCH AND DEVELOPMENT

"Sec. 701. (a) Findings.—The Congress finds that—

"(1) Existing automobiles, on the average, fall

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short of meeting the long-term goals of the Nation with respect to providing safety, to protecting the environment, and to conserve energy.

"(2) With additional research and development, several advanced alternatives to existing automobiles have the potential to be mass produced, at a reasonable cost, with significantly less environmental degradation and fuel consumption than existing automobiles, while remaining in accordance with other requirements of Federal law.

"(3) Insufficient resources are being devoted, both by the Federal Government and by the private sector, to research and development of advanced automobiles and automobile components.

"(4) An expanded research and development effort into advanced automobiles and automobile components by the Federal Government is needed to complement and increase such efforts by the private sector and to encourage automobile manufacturers to seriously consider such advanced automobiles and automobile components as alternatives to existing automobiles and automobile components.

"(5) Because of the urgency of the energy, safety, and environmental problems, such advanced automobiles and automobile components should be developed, tested, and prepared for manufacture within the shortest practicable time.

"(b) PURPOSES.—It is therefore the purpose of the Congress in this title—

"(1) to direct the Administrator of the Energy Research and Development Administration to take such steps as he/she deems necessary to insure the development, within four years from the date of enactment of this Act, or otherwise within the shortest practicable time consistent with appropriate research and development technique, of at least one prototype automobile which—

"(A) without further technological research or demonstration, could be adapted by the private sector for mass production and sale at retail in quantities exceeding ten thousand vehicles per year;

"(B) would present the least practicable total amount of energy consumption and environmental degradation taking into account—

"(1) the type and quantity of energy resources necessary to operate and maintain each such vehicle under typical conditions of operation;

"(2) the type and quantity of energy resources required for the commercial production and for the disposal of each such vehicle;

"(3) its energy consumption requirements;

"(4) its exhaust emissions;

"(5) the noise characteristics associated with its operation;

"(6) the environmental consequences associated with its production and disposal; and

"(7) such other environmental costs as the Administrator identifies;

"(C) would represent a substantial improvement over automobiles having internal combustion engines with respect to the factors listed in paragraph (B);

"(D) would have operating characteristics at least comparable to those of automobiles having internal combustion engines with respect to—

"(1) acceleration;

"(2) cold weather starting;

"(3) cruising speed; and

"(4) other performance factors;

"(E) would not, because of the energy source or technology utilized, create any usual or significant health or safety risks;

"(F) could be produced and operated in compliance with all Federal requirements pertaining to—

"(1) exhaust emissions;

"(2) noise pollution;

"(3) occupant safety;

"(4) damage resistance; and

"(5) any other federally regulated matters;

and

"(G) could be mass produced, operated, and maintained at the lowest practicable economic cost given the other requirements of this subsection.

"(c) On January 1 of each calendar year, the Administrator shall submit a report to the Congress on the progress made toward meeting the requirements described in subsection (b) (1) of this Act. In the event the Administrator determines that these requirements cannot be met, such report shall specify the reasons therefor and shall recommend a revised schedule for the attainment of such requirements.

"Sec. 702. There are authorized to be appropriated funds not to exceed $ to carry out the purposes of this Act.

"Sec. 703. As used in this title, the term—

"(1) 'Administrator' means the Administrator of the Energy Research and Development Administration;

"(2) 'prototype automobile' means a personal use transportation vehicle propelled by fuel, which is energy efficient, safe, damage resistant, and environmentally sound;

"(3) 'damage resistance' refers to the ability of an automobile to withstand physical damage when involved in an accident.".

TESTIMONY BY
JAMES C. CORMAN
BEFORE
SUBCOMMITTEE ON ENERGY RESEARCH,
DEVELOPMENT AND DEMONSTRATION
WITHIN THE COMMITTEE ON SCIENCE AND TECHNOLOGY

MR. CORMAN: Mr. Chairman, thank you for affording me this opportunity to testify before this Subcommittee on H.R. 6354, the Automotive Transport Research and Development Act of 1975, in conjunction with your proceedings on electric vehicle research. The measure I bring to your attention today is designed to stimulate the search for an advanced automobile which meets the needs of smog choked cities and the needs of consumers and the nation for fuel efficiency.

The major automakers have failed to keep in step with our needs for energy efficient, low polluting automobiles. As we all know, the automakers have chosen to stick with the internal combustion engine with add-on devices to control air pollution. In making this decision we have seen fuel economy averages plummet in recent years to an average of 13 miles per gallon.

At the same time, smog continues to choke our cities with little substantial relief in sight. As it is in many other areas of the country, the leading cause of air pollution in the Los Angeles basin, which comprises a good share of my district, is the automobile. While we obviously cannot live without the automobile, we must make every practicable effort to insure that the automobiles we drive will neither choke us nor starve our pocketbooks.

It is really no surprise that the automobile industry has chosen to place most of its effort in engines which have been in widespread use for more than 60 years.

The automobile industry is intimately familiar with the engine and obviously has made a large commitment to it. The research budgets of the major automakers show vividly that research and development resources have shifted away from alternative technology and into improvements in the internal combustion engine. For example, the average amount of research and development dollars spent by the Ford Motor Company in the years 1967 through 1969 on alternative power systems was approximately 25%. This figure dropped to 17% through 1969 and only 2.3% from 1970 to 1972.

Alternative engines show great promises. For example, Stirling cycle engines apparently will be able to meet fully the emission standards set in the 1970 Clean Air Act for 1976 models while at the same time doubling fuel economy compared to existing internal combustion engines. The diesel engine can get up to double the mileage of internal combustion engines and might be a promising alternative if problems of oxides of nitrogen emissions, performance, noise and odor can be solved.

Rankine cycle engines, using the principle of the steam engine, can easily achieve the emission standards contained in the 1970 Clean Air Act and with further research could offer fuel economy far in excess of present internal combustion engines.

The Administration's lack of support for such technological advances is exemplified in the Environmental Protection Agency's funding - an approximate annual rate of $7.2 million per year. The Federal Government's token contribution to this effort, drastically curtails the talents and innovations of private entrepreneurs. Given the importance of the automobile in society and its effect on air pollution and energy reserves these efforts should not be wasted.

The bill I offer today for your consideration is designed to stimulate the search for an advanced automobile by requiring the Administrator of the Energy Research and Development Administration to insure the development of a prototype automobile capable of being put into production in quantities exceeding 10,000 per year. As it is necessary to put in a time period to adequately prod these efforts, the bill provides that such an automobile be developed in 4 years. If the 4 year period cannot be met, the Administration is to report to the Congress on its reasons therefor and suggest a new timetable. The automobile to be produced must present the least total amount of energy consumption and environmental degradation practicable and should be capable of mass production at the lowest possible cost consistent with the requirements of the bill. Finally, the automobile must be capable of being produced, distributed, operated and disposed of in compliance with any Federal law including emissions control, noise, safety, and damage resistance.

It is essential that the Federal Government provide such direction and commitment in order to conserve energy and control air pollution.

Mr. Chairman, I am grateful to you and your Subcommittee for considering this measure and urge you to incorporate H.R. 6354 into related vehicle research, development and demonstration legislation. Thank you.

VESPA CIAO

Vespa Southwest, Inc.

2539 UNIVERSITY • HOUSTON, TEXAS 77005 • (713) 524-8251

VESPA SCOOTER

June 27, 1975

Hon. Mike McCormick, Chairman
Committee on Science & Technology
Suite 2321 Rayburn House Office Bldg.
Washington, D.C. 20515

Dear Mr. McCormick:

You are to be congratulated for your insight into our energy problem. While technology that is available today is far from the ultimate answer in Electric Vehicle transportation, it certainly is adequate for a large segment of our population, both commercial and personal.

We have been a Dealer for the Seabring Vanguard Electric CitiCar here in Houston for the past eleven months. During this period we have sold over 100 CitiCars to commercial and individual customers. The Citicar has performed exactly as specified and all users are very satisfied with their Electric CitiCars.

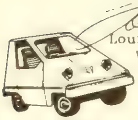
The bill which you have proposed is an excellent step in the right direction, however I do take issue with one aspect of this bill. I do not feel it is practical to convert existing automobiles to electric power. Installing 16 to 20 or more batteries in a compact or sub-compact will increase the weight to about 4000 or 4500 lbs. The electricity cost and the battery replacement cost would be prohibitive for the average family.

The only logical solution is to design and build from the ground up an Electric Car, just as Sebring Vanguard, Inc. did in the CitiCar. It would seem very advantageous to the American public to subsidize in some way those Companies who have already proven their ability to build Electric Cars.

We would appreciate having this letter appear in the printed hearing volume and look forward to the passage of H.R. 5470 including some of the thoughts stated above.

Sincerely,

Louis J. Daleo
Vespa Southwest, Inc.



ELECTRIC
CitiCar

Westinghouse

EAGLE-PICHER INDUSTRIES, INC.
ELECTRONICS DIVISION • P.O. BOX 47, JOPLIN, MISSOURI 64801

22 July 1975

JUL 24 REC'D

Honorable Mike McCormack
Sub-Committee on Energy Research,
  Developing and Demonstration
House of Representatives
U. S. Congress
Washington, D. C.

Subject: H. R. 5470, Electric Vehicle Research, Development and Demonstration Act of 1975

Gentlemen:

As suggested by your letter transmitting a recent energy questionnaire, we would like to present our comments on the subject Electric Vehicle Research, Development and Demonstration Program. These comments are based on our knowledge and experience in the advanced battery technology field. Eagle-Picher's position in the battery industry is unique because we manufacture a large number of different electrochemical couples or systems, many of which can be or currently are directed toward electric vehicle propulsion.

For example, we are presently conducting development or investigative programs in such systems as advanced lead acid, nickel-iron, nickel-zinc, nickel-hydrogen, zinc-air, iron-air, lithium-sulfur, and sodium-sulfur batteries. In addition, Eagle-Picher has over 25 years of experience in many other electrochemical systems including silver-zinc, nickel-cadmium, lithium-organic electrolyte, water-activated and thermal battery types. Eagle-Picher is also experienced in electric vehicle applications by virtue of: (1) our design and development of seven experimental or test vehicles, and (2) the manufacture of several hundred multi-purpose personal electric vehicles.

We wish to submit the following comments for your consideration:

1. The present state of development of batteries limits the performance of electric vehicles;

2. Driving range will be limited because of the unavailability of advanced batteries in a production configuration;

3. Limited driving range and degraded performance will result because of the H. R. 5470 restriction to utilize "a conventional chassis" because relatively heavy electric vehicles will result from this decision;

4. Limited driving range and reduced performance would cause adverse public reaction to electric vehicles and could impede eventual consumer acceptance.

Therefore, we recommend that the number of electric vehicles in the first year be reduced from 5,000 to 500 or less. We further recommend that increased emphasis be placed on development of advanced batteries using technology available in the near term. Examples of such systems are advanced lead-acid, nickel-iron and possibly nickel-zinc.

We are in favor of the demonstration goal of this program. We sincerely believe that electric vehicles can be developed in three years that will meet the needs of the industrial and consumer public. We believe that the 5,000 vehicles to be procured in the third year of the program would advance the technology and acceptance of the electric automobile as a substitute for internal combustion vehicles. However, we are concerned that the first year's program of putting 5,000 state-of-the-art electric vehicles utilizing conventional chassis and existing state-of-the-art batteries will seriously, if not irreparably damage the case for electric vehicles. The lower level of 500 or less vehicles should accomplish most of the goals the first year's program which are to determine capabilities of the existing state of the art, accumulate statistical data, and by analysis of public reaction to these vehicles, determine areas to be improved in the subsequent development of vehicles for the latter phases of the program.

The current state of the art in lead acid batteries will provide approximately 200 deep discharge cycles operation and 11 WH/Lb at the two hour discharge rate. These batteries typically are modifications to automotive and golf cart battery types. Advances in heavy-duty lead acid battery technology have suffered because sufficient funding has not been made available to develop a lead acid battery specifically designed for the electric vehicle application. It is possible using a combination of known technology to develop lead acid batteries that will be ready for the three year demonstration program that will have 50% more energy density and five times more cycle life.

Near-term batteries also include nickel-iron and nickel-zinc. These systems are worthy of funding by virtue of their advanced state of development. Electric vehicle batteries in the nickel-iron and nickel-zinc system should be capable of providing 28 to 31 WH/Lb at high power discharges. These batteries would be ideally suited for electric vehicles as this performance is two and a half times that available with state-of-the-art lead acid batteries. There is little doubt that these batteries could be ready for incorporation in electric vehicles within three years. Development funding would speed improvements in: (1) economical manufacturing methods, (2) optimize nickel-iron energy density, and (3) increase nickel-zinc cycle life.

We would like to stress that every user application requires a unique battery design and electric vehicles are no different. In our advanced, special purpose battery design and development experience, we have witnessed tremendous advances in battery technology when specific problems or problem areas have been identified and adequate resources have been made available for problem solving. The space program is one example of what can be accomplished given a goal and adequate interest or sponsorship. Eagle-Picher firmly believes that the necessary battery, controller, drive, and charge systems for electric vehicles can be developed in 3 to 5 years if people become committed to that goal.

Should you desire specific technical information, we will gladly meet with members of your staff at their convenience. Please have them contact either Earl Carr or Jim Black for specific arrangements or additional information.

Sincerely yours,

Eagle-Picher Industries, Inc.
ELECTRONICS DIVISION

James M. Dines

James M. Dines
General Manager
Couples Department

JMD/sc

DOUGLAS DOW
CONSULTING ENGINEER

P.O. BOX 3333
DETROIT, MICHIGAN 48214

MEMBER OF SOCIETY OF AUTOMOTIVE ENGINEERS
ELECTROCHEMICAL SOCIETY

(313) 823-1431 / (313) 821-4900

May 30, 1975

TO: Honorable Mike McCormack
Chairman Sub-Committee on Energy Research, Development and Demonstration of Committee on Science and Technology

RE: Electric Vehicle Research, Development and Demonstration Act of 1975 - H.R. 5470

FROM: Douglas Dow, Consulting Engineer

As a consulting engineer whose major interest for the last 12 years has been electric vehicles, I wish to strongly urge passage of this bill. As a life long resident of Detroit, I know that the automobile industry cannot and will not undertake production of electric vehicles unless they are assured of an immediate market of at least 100,000 vehicles a year. The electric light and power industry who are the logical developers and promoters of a new electrical appliance "that goes places and takes you with it" have been blocked by the regulatory commissions.

It is of the utmost importance that electric vehicle development be completely separated from the development of other "alternative systems". When grouped with other alternative systems under EPA there has been absolutely no progress for the last five years. The proposal to continue this arrangement covered by Senate Bill 783 would, in my opinion, block progress for another five or ten years.

Battery research is needed for the long run, but a viable electric vehicle can be built today with today's batteries, if the concept of limited performance is accepted. By limited performance I mean a two or three passenger vehicle with a top speed of 40 to 45 miles per hour and a range of 40 to 60 miles per charge designed specifically for urban traffic. To be commercially acceptable such a vehicle must be low cost. The American public will not, in my opinion, pay a premium price for limited performance. This calls for innovative technology to produce a light weight, but safe, low cost, energy efficient vehicle. It cannot be done by electrifying an existing internal combustion engine vehicle, which has been designed throughout on the assumption of plentiful low cost gasoline. It can only be done by making a complete break with existing automotive engineering and starting from scratch, with new tires, wheels, suspension, frame, streamlined bodies, and collision energy absorbing safety systems.

Half of the gasoline used today by passenger vehicles is used on trips of not more than 10 miles long. To the extent that electric vehicles can be substituted on such trips, at least half of this petroleum energy can be saved even if the electricity is made from oil and all of it if made from coal or nuclear energy.

H.R. 5470 recognizes the problem and offers a well co-ordinated balanced approach toward solving the problem.

Respectfully submitted,

Douglas Dow

Douglas Dow
Consulting Engineer

INTRODUCING
DOUGLAS DOW

ENGINEER

Professional Mechanical Engineer

Former Chief of Research, Chairman - New Uses Committee
The Detroit Edison Company

Former President - The Detroit Testing Laboratory

Charter Member - Engineering Society of Detroit

Former Chairman - Laboratory Management Committee - American Council of Independent Laboratories

Society of Automotive Engineers - Tau Beta Pi

Electro Chemical Society - Sigma Xi

Chemical Society of Great Britain

CITIZEN

Trustee Emeritus - Cranbrook Institute of Science

Trustee - McGregor Fund

Former Commissioner Purchases & Supplies - City of Detroit

Former Commissioner & President - Detroit Water Board

Former Commissioner & Chairman - Michigan Mental Health Comm.

Former Trustee - Wayne University Foundation

Charter Member - Detroit Committee on Foreign Relations

SOLDIER

Colonel - U.S. Army Reserve - Retired

Active Duty - 1940-1945

Called to Washington in 1940 by William S. Knudsen because of previous experience in governmental purchasing

Spearheaded development and launch program for military vehicles including the jeep

Served as Battalion Commander and on Procurement Staff - China, Burma, and India Theater

Graduate - Command & General Staff School - Ft. Leavenworth

DOUGLAS DOW
CONSULTING ENGINEER

MEMBER OF SOCIETY OF AUTOMOTIVE ENGINEERS
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P.O. BOX 3333
DETROIT, MICHIGAN 48214
(313) 823-1431 / (313) 821-4900

July 1, 1975

The Honorable Mike McCormack, Chairman
Subcommittee on Energy Research,
Development, and Demonstration
Committee on Science and Technology
U. S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D. C. 20515

[illegible]

Dear Sir:

I am happy to take this opportunity to amplify several points stated briefly in my previously submitted letter of May 30th (copy attached) which I will be delighted to have included in the record.

Why "new tires and suspension"? Some 15 years ago the National Bureau of Standards reported on tests of the rolling resistance of American passenger car tires as nineteen lbs per 1000 lbs of vehicle and of truck tires as nine pounds per 1000 lbs. Automotive industry passenger car designers have found it easier to design the ride into the tires rather than in the suspension. The penalty in terms of cheap gasoline and an 11.5% efficiency internal combustion engine was not great. One SAE report stated that "under steady running conditions the fuel consumption of two medium performance cars was improved by only some 5% when the rolling resistance of the tires was reduced by 20%". The trucking industry however, where gasoline was an important part of operating costs, insisted on the lower rolling resistance tires and built the ride into the driver's seat. Furthermore, electric power stored as chemical energy in a storage battery is a highly available (or low entropy) highly ordered form of energy. The Rankine cycle losses have been removed in the steam turbine generating plant. Motor efficiencies in the vehicle of 65% are minimal, 80% is readily available and 90% is available at a price. Cutting rolling resistance in half by changing to high pressure tires and a well designed suspension makes a very significant improvement in an electric vehicle.

The higher efficiency is essential not so much for the cost of the electric energy at the meter but to reduce the weight of the battery required to store it. With today's lead-acid batteries, it is necessary to have from one-third to one-half of the vehicle weight in battery to get a 40 to 60 mile range, so that for every pound saved in chassis weight another pound of battery may also be saved.

The American automobile industry contends that regenerative braking is not useful because it will not extend the range ten percent. (See G.M. presentation -- attachment D, page 5, paragraph 5.) However, the Germans are reporting an increase in range of 30% in urban traffic stop-and-go driving. In tests run in 1968 by the Detroit Edison Company Research Department on a very inefficient small electric vehicle, energy recovery by regenerative braking was increased from 12% to 19% by merely increasing the tire pressure from 19 p.s.i to 50 p.s.i.

Why "new wheels"? When the low rakish sport-car look became stylish, automotive designers again took the easy path and reduced wheel size, again increasing rolling resistance. Electric cars do better with large diameter wheels.

Why "new frame design"? Today's passenger car designs, tooling and assembly lines are all based on bent frames with a "toe in" in front and a "kick up" in back. These frames will not support the high energy-absorbing bumper systems which are necessary to obtain the safe lightweight construction essential to make proper use of a high efficiency battery electric drive system with regenerative braking.

Why "streamlined bodies" on low speed vehicles? Today's automobile designers do not consider streamlining to be as important as "style". Because of the high rolling resistance and consequent losses in today's passenger cars, drag resistance is of such minor importance that it is not even considered in the standardized E.P.A. dynamometer mileage rating tests. However, when weight is reduced and larger wheels and higher pressure, more efficient tires are used, wind resistance becomes quite important.

A 1967 SAE Paper (#670177) by Tenniswood and Graetzel of Ford Motor Company reported that the aerodynamic losses equalled 50% of the total power losses at about 48 miles per hour for a compact 4-passenger car.

However, for a modern, well designed, lightweight, low rolling resistance urban electric vehicle aerodynamic drag can equal 50% of total power loss at as low a speed as 24 miles per hour. And by changing from a Coefficient of Drag of 0.8 (1930 Model A) to a Coefficient of Drag of 0.3 (Porsche coupe) total power required for steady driving at 40 miles per hour can be cut in half.

One of the very strong points of H. R. 5470 is the recognition of the place of electric vehicles with today's batteries as a "limited performance vehicle" and separating the program for research development and demonstration from that of other "alternative systems". This point cannot be over emphasized. I talked to EPA in Ann Arbor, Michigan in August of 1971 and was informed then that on the advice of the "ad hoc" industry advisory committee no electric vehicle could be considered under the "Federal Clean Car Incentive Program" (FCCI) or the "Advanced Automotive Power Systems Program" (APCO) unless it could carry four passengers 85 miles per hour for one mile and 200 miles per charge at 70 miles per hour. There was no change in attitude when I talked with them again on February 5 of 1974 and December 12. As late as early 1975 inquiries to six different agencies in Washington as where to go for assistance on electric vehicle development were all referred to EPA. Now the advanced automotive power systems branch of EPA has been merged into ERDA and Dr. Kane's presentation differed only slightly from that of General Motors and Professor Thornton's. "Go slow", "wait awhile", "let industry do it", "batteries first".

On May 22, 1975, I initiated correspondence with ERDA and my responses to date do not indicate any significant changes in attitude toward electric vehicles as a possible "alternative power system" from that of 1971.

There were several mentions during the hearing of the "Los Angeles Report". This first surfaced in February 1974 at the Third International Electric Vehicle Symposium as paper no. 7470 by Graham Hagey and William F. Hamilton. Then in October 1974 it came out as NTIS PB-238877 - "Impact of Future Use of Electric Cars in the

Los Angeles Region" and then on 8 May 1975, in the form included in the General Motors presentation (Attachment F) at the hearings and included [illegible] additional data in St. Louis and Philadelphia.

It is interesting to note that in the first form it included data on two electric cars with lead acid batteries. The data on the lighter weight 2,100 pound, two-passenger limited performance vehicle with 550 pounds of battery was omitted from the two later forms of the study which included only the four-passenger car weighing 3,975 pounds with 1,500 pounds of battery, thus strengthening the case for high battery replacement cost. Neither car represented any advanced chassis design of the type I have been discussing above.

The whole concept of "wait for batteries" and "battery research now -- vehicles later" breaks down when consideration is given to a well designed lightweight but safe limited performance electric vehicle. Today's golf cart battery was not developed until after golf carts became popular and created a market.

Section 9(a) of H. R. 5470 calls for a study of inhibiting factors and the Representative from West Virginia, Mr. Hechler, frequently questioned witnesses on this subject. One of the witnesses from Ohio mentioned the withdrawal of support by a local utility because of action by the State Regulatory Commission. This also happened in Michigan and Illinois and, I believe, in Connecticut.

Electric utilities could be of tremendous help in servicing and the promotion of electric vehicles in the early stages of their development just as the utilities have done with other electrical appliances.

Thank you for this opportunity to amplify my comments in my one-page letter of May 30th.

Respectfully submitted,

Douglas Dow,
Consulting Engineer

P. S. (not for the record) I could also amplify the discussion of energy-absorbing safety systems, the relationship of the battery industry to the automotive industry and the history and future of battery research for vehicles and for stationary energy storage, but your July 3 deadline does not permit. May I also suggest that your staff review the extension of remarks by Representative Burton in the Congressional Record of Thursday, May 18, 1971, Vol. 117, No. 73, pages H-4063-4074? Again, thanks,

D. D.

Westinghouse
Electric Corporation

1801 K Street N W
Washington D C 20006

June 26, 1975

Representative Mike McCormack
U.S. House of Representatives
Rayburn House Office Building
Suite 2321
Washington, D.C. 20515

Dear Congressman McCormack:

With regard to your letter of June 23, I am pleased to report that Westinghouse has submitted a statement for the record of the June 3, 1975 hearings on HR-5470. Our submittal was dated June 18 and, therefore, crossed with your letter. I have included an additional copy of the submittal for your personal use and information.

Thank you for your interest.

Sincerely,

Ray Durante

Raymond W. Durante
Assistant to the Vice President
Government Affairs

enclosure

Westinghouse Electric Corporation

Research and Development Center

Beulah Road
Pittsburgh Pennsylvania 15235

June 18, 1975

Dr. Lloyd Curry
Science Consultant
House Science and Technology Committee
Subcommittee on Energy Research, Development
and Demonstration (Fossil Fuels)
B. 374 Rayburn House Office Building
Washington, D. C. 20515

Dear Dr. Curry:

Enclosed is a statement we would like to submit for inclusion in the record of the June 3, 1975 Hearing on The Electric Vehicle Research, Development and Demonstration Act of 1975, H. R. 5470. We appreciate the opportunity to provide this information and assure you of our availability to your committee for discussions or to supply additional details as might be desired.

Also enclosed are a paper presented by Westinghouse scientists at the 1974 Electric Vehicle Symposium and a copy of the Westinghouse Nuclear Energy Digest which contains an article on electric vehicles, as well as several other articles on energy and related topics. I believe you will find these of interest.

Very truly yours,

George Mechlin

George F. Mechlin, Vice President
Research & Development

Enclosures

United States House of Representatives Science and
Technology Committee

Subcommittee on Energy Research, Development and Demonstration

Hearing on H. R. 5470:

The Electric Vehicle Research, Development and Demonstration Act of 1975

June 3, 1975

Submittal by: Dr. George F. Mechlin
Vice President, Research & Development
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

The Westinghouse Electric Corporation is a major producer of equipment for the production, conversion, storage, and utilization of energy. In our varied manufacturing and other operations, we are also a significant user of energy in many forms. Because of this background and recognizing our responsibilities as a good corporate citizen, we have over the years had a very active interest in the United States energy supply situation, problems associated with it, and possible solutions. Many of the results of our research and analyses in this area have been published and are matters of public record. For this reason, I will present here only a brief review of several points of particular significance to this hearing. We, of course, would be pleased to be available to the subcommittee for additional discussions or to supply more detailed information as might be desired.

Although there are varying interpretations of the dimensions of the problem, there is virtually unanimous agreement that we are facing a worldwide energy crisis. This crisis has both short-term (the next decade) and long-term (the end of this century) aspects. Although the energy supply situation is global in scope, there are particularly critical problems facing the United States. Not only petroleum fuel availability, but also national security, balance of payments, and potential environmental impact become important considerations in our national picture. The implications to our national well-being and the possible alternatives open to us have been discussed at length by many concerned groups and individuals over the last several years. One is led inevitably to the conclusion that the United States must achieve independence of foreign petroleum fuel supplies as expeditiously as possible and must accomplish this in such a way as not to stifle growth of the economy in the process.

Our analysis of the United States' energy crisis convinces us that there is no single, easy solution. Rather, it must be attacked on a massive scale on three fronts. First, in the short-term, we must increase domestic production of oil and gas by every possible means, including offshore drilling, deep well drilling, and synthesizing oil and gas from coal. Second, we must conserve energy through improved end use efficiency (smaller cars, better insulation, etc.). Third, in the long-term, we must find other ways of meeting the energy demands now supplied by oil and gas. In other words, we must begin now to find substitutes for these fuels.

Substitution of energy utilization in electrical form in uses traditionally employing direct utilization of petroleum fuels offers the most practical means of achieving the required substitution. It provides flexibility as to the primary fuel employed, specifically including coal and nuclear fuels as well as utilization of geothermal, wind, tidal, and solar energy sources as they may be developed. The optimum primary energy source will vary depending upon location and time. Utilization of energy in electrical form isolates the end use from the primary source and facilitates optimization of the total energy system.

Looking ahead to the year 2000, we have examined what happens if we substitute electricity (from nonpetroleum sources) for direct use of oil and gas in as many end use applications as are technically and economically feasible giving special emphasis to saving oil and gas wherever possible for those uses for which it is uniquely suited, that is, petrochemical feed stocks, aircraft, and large trucks. We also assume that some combination of government regulations and higher fuel prices will cause significant conservation practices to be adopted such as smaller cars, more efficient appliances, better thermal insulation, etc.

We conclude from this analysis that the United States petroleum fuel requirement for the year 2000 can be reduced to approximately one-third of what it would be assuming no cost, availability or other restraints. This requirement is one that could be handled by projected domestic petroleum fuel supplies.

A key element of this scenario is the substitution of electrical energy for approximately 50 percent of the nation's transportation energy requirement, now provided almost entirely by direct combustion of petroleum. Those portions of the transportation sector for which such substitution seems feasible include urban-use passenger cars, urban delivery trucks, intra-city buses and rapid transit, and all freight and passenger trains. We also assume that trains will take over half of the inter-city freight traffic from trucks and 10 percent of passenger traffic from airplanes. If anything like this scenario is to take place, and the alternatives are few, then we must begin now to take the steps that will make it possible and cause it to happen. The type of legislation being considered by this subcommittee can be a key step in this direction.

Specifically addressing the Electric Vehicle Research, Development, and Demonstration Act of 1975, we would like to make several points.

It is technically possible now to substitute electrically-powered vehicles for gasoline-powered vehicles performing some everyday tasks. The performance requirements of the missions normally performed by some urban light delivery and passenger carrying vehicles are within the capability of present electric vehicle technology. Confirming data exists in the United States Postal Service experimental electric vehicle fleet at Cupertino, California, and their subsequent order for 350 lead-acid battery powered one-quarter ton vehicles. The fact that over fifty thousand electric delivery vehicles are operating in England with favorable economics, and the sale and use in the United States of approaching one thousand two-passenger commuter type vehicles is also indicative that useful, even though severely limited, tasks can be performed.

It appears unlikely, however, that such vehicles will spontaneously come into sufficiently widespread use to have any significant impact on our national petroleum fuel consumption. To attain such a degree of utilization, an electric vehicle would have to exhibit a combination of performance, flexibility, and economics which is not attainable with commercially available battery technology, even with the use of optimally designed electric vehicle propulsion, control, and construction.

It can be fairly stated that no battery technology now on the horizon, including the most advanced high temperature cells on which some research is being carried out, offers the capability to provide an electric vehicle with the acceleration, speed, and range performance flexibility of a gasoline powered vehicle. However, each improvement in the power source and propulsion components will extend the electric vehicle performance and hence offer increased possibility for further substitution and consequent conservation of our petroleum energy resources. We have concluded from extensive electric vehicle use tests that, in the near term, an improvement in energy storage capability per pound of battery by a factor of two or three over that which is presently possible with lead-acid batteries in electric vehicle propulsion use would offer the first significant step upward in meeting the needs for the application of electric vehicles to a much wider spectrum of uses, providing, of course, the battery cost and service life are such as to make the overall vehicle system cost effective.

Our second point relates to the efficiency of primary energy utilization in electric vehicles. We have actual data from instrumented vehicles operated over typical postal routes in the Pittsburgh area which shows a 50 percent reduction in primary fuel energy consumption for an electrically powered delivery vehicle as compared to the conventional gasoline powered vehicle. This demonstrates that in the kind of stop-start service typical of delivery and many other urban uses of vehicles, the extremely low efficiency of gasoline engine propulsion far outweighs the energy losses associated with the conversion of fuel energy to electrical form. Thus, any electric vehicle substitution in this type of service results in a net petroleum fuel savings even if petroleum fuel is the prime energy source for the electrical power generation. Of course the flexibility of primary energy source inherent in the utilization of energy in electrical form also admits the possibility of more substantial petroleum fuel savings through the use of more plentiful primary energy sources such as coal or nuclear. Throughout the United States only 17 percent of our primary fuels for electrical generation are derived from petroleum, whereas 95 percent of our transportation fuel is derived from petroleum.

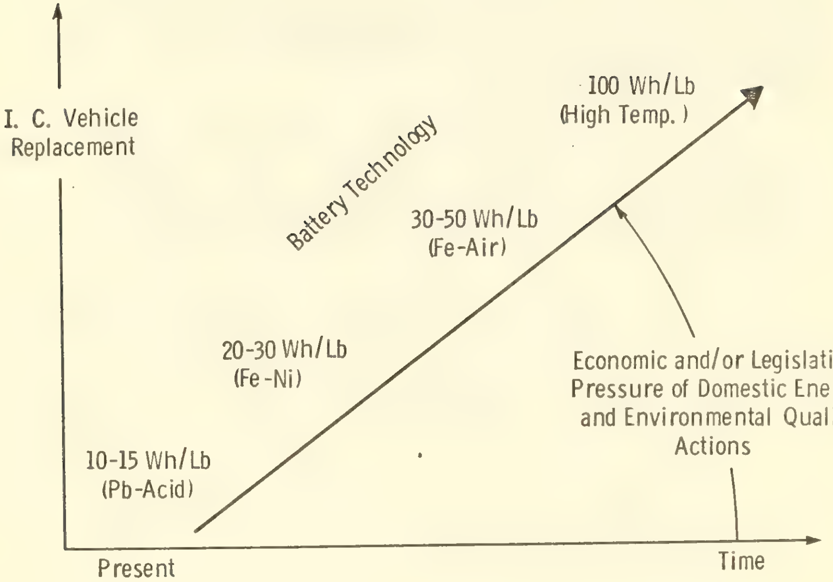
The third point we would like to make is that even very widespread use of electric vehicles will not severely tax present or projected-future installed electric power generation, transmission and distribution capacity. Most envisioned uses would be conveniently served by a mode of operation employing overnight battery recharging. This would permit the utilization of electrical power generating capacity which must be present and available for peak power requirements but which would otherwise be idle during night-time off peak hours. In fact, a modest leveling of electrical power system load could be achieved, a desirable feature from a fuel conservation standpoint since high efficiency base load generation equipment would be used. To cite some specific numbers, a fleet of one million electric vehicles performing light delivery tasks would utilize less than one percent of the approximately 400 Gigawatt present installed electrical powered generation capacity. Looking further into the future, a fleet of one hundred million electric vehicles (approximately the total number of vehicles operating in the United States today) would utilize only 12 percent of the two thousand Gigawatt generating capacity projected by many sources to be installed in the United States by the year 2000. From an installed capacity standpoint, it therefore seems entirely realistic to imagine a substantial portion of the United States transportation energy requirement to be supplied in electrical form, thereby permitting flexibility of choice of primary energy source.

In conclusion, we are convinced that, while presently available electric vehicles and batteries can provide a beginning for the limited substitution of electrically-powered vehicles for gasoline powered in the United States, better performance and economics are required for significant progress in this direction. Some of the needed improvement can be accomplished through application of advanced technology already developed and demonstrated on laboratory and pilot scale. Lightweight vehicle structures, higher performance batteries, and significantly more efficient drive systems are all achievable by this means. The Westinghouse Research and Development Center, both on our own and with the cooperation of automotive manufacturers, has fabricated experimental electric passenger vehicles powered by specially designed iron-nickel batteries and unique electrical drive trains. Extensive tests on these vehicles and regular use experience in representative situations indicate significant performance improvement over anything obtainable in more conventional electric vehicles. Analytical projections indicate favorable life cycle economics as compared to gasoline powered vehicles performing comparable tasks. Even so, much research and development remains to be done, especially on advanced energy storage technology, in order to bring about further improvement in electric vehicle performance and to broaden the scope of their application.

Figure 1 depicts graphically an evolution from the present situation of severely limited utility electric vehicles with consequent little prospect of significant utilization through vehicles exhibiting performance and economic parameters which make them attractive substitutes for gasoline powered vehicles in a significant portion of their uses. Only through such an evolution can the needed substitution of electrical energy for direct petroleum use be accomplished in the transportation sector. As shown, the timing depends both upon technological advances and governmental incentives.

Researching, developing, and producing limited quantities of new battery and vehicle systems is an extremely costly, time consuming, and risky venture. We have invested many millions of dollars in these programs with no governmental support. Capital requirements for commercialization of these developments are large, and an industrial enterprise must inevitably weigh the investment against the magnitude, timing and probability of the return. An electric vehicle embodying the most advanced technology realistically foreseeable will still be limited in range compared to the gasoline powered vehicles we are accustomed to and its initial cost will likely be one and one-half to two times as great although life cycle cost may be lower. It will not be the preferred purchase unless the cost of fuel and operation of a gasoline vehicle increase so substantially over present levels that the higher acquisition cost of the electric is dramatically offset in the overall life cycle cost picture. Faced with this kind of market uncertainty, the private sector is not in a position to make the kind of investment needed to bring electric vehicles to widespread commercial reality. It appears that government must provide the impetus.

It is our recommendation that government and industry begin quickly to formulate a joint and balanced plan covering a spectrum of work from research to significant fleet demonstrations. This should cover new battery, propulsion, control, and construction concepts, including research, prototype, construction, and fleet demonstration programs. The program should also encourage and sponsor urban planning directed toward an environment less tailored to the characteristics of gasoline powered vehicles and more adapted to electrically powered transportation. Incentives for the use of electrically powered vehicles wherever possible should be provided through appropriate tax and or fee provisions. Investment of public funds in this type of program will further petroleum fuel conservation through substitution of electrical for gasoline powered vehicles by providing for the development of both advanced electric vehicle technology and a viable electric vehicle market, both prerequisites to making suitable vehicles economically available to users. This would provide the impetus and the means for implementing a key element of an overall strategy which can provide long-term energy independence for the United States.


I. C. Vehicle Replacement
Battery Technology
100 Wh/Lb (High Temp.)
30-50 Wh/Lb (Fe-Air)
20-30 Wh/Lb (Fe-Ni)
10-15 Wh/Lb (Pb-Acid)
Economic and/or Legislative Pressure of Domestic Energy and Environmental Quality Actions
Present
Time

STATEMENT OF NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION ON H.R. 5470 "ELECTRIC VEHICLE RESEARCH, DEVELOPMENT, AND DEMONSTRATION ACT OF 1975" BEFORE THE SUBCOMMITTEE ON ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION, COMMITTEE ON SCIENCE AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

JUNE 6, 1975

My name is Lowell Endahl. I am Coordinator of Research and Technological Development for the National Rural Electric Cooperative Association (NRECA), the national service organization of some 950 consumer-owned cooperatives which provide electric service to about 25 million people in the rural and sparsely populated agricultural areas of 46 states, and in 2600 of the nation's 3100 counties.

We appreciate this opportunity to comment on H.R. 5470 and to voice support on behalf of rural electric cooperatives throughout the nation for a Federal program of research, development and demonstration to promote electric vehicle technologies and to demonstrate the commercial feasiblity of electric vehicles. It is our purpose to bring to your attention some of the specific and perhaps unique requirements of consumers living in rural areas and to transmit to you the wishes of our membership as stated in resolution.

The NRECA member rural electric systems at their annual meeting in January of this year (attended by 10,529 delegates and officials) adopted the following resolution:

> "ELECTRIC VEHICLE RESEARCH -- A viable electric vehicle would significantly reduce the consumption of non-renewable resources and help to eliminate the major source of air pollution. Research toward developing such a vehicle is now underway, and the successful completion of such efforts could significantly affect the load patterns and requirements of rural electric systems. We support electric vehicle research efforts now underway and urge further involvement and effort by others, including the Federal government, to expedite this important development. We also urge that in conjunction with this research, studies be undertaken to determine the changes in electric system loads that may result from such a development."

Rural electric systems have long been interested in electric vehicle development for several reasons:

1. Rural electric cooperatives serve well over half of the farms in the nation and these farms produce over 65% of total agricultural products (78% of the wheat). Farms present an unusual, and excellent opportunity to test and use electric vehicles, particularly in the initial stages of development. Farmers have the expertise and the mechanical ability to evaluate and properly main-

tain such equipment.

2. Farms offer a good potential market for a wide variety of electric vehicles with medium to slow speeds and short range characteristics.

3. Rural electric systems serve a large number of rural people who work in nearby communities but have no access to mass transportation and therefore must commute in private autos.

4. Rural electric systems serve predominently farm and rural residences with few industries and commercial establishments and therefore because of lack of load diversity, generally have lower load factors than other metropolitan based utilities. Electric vehicles, with batteries charged at off-peak hours could add substantially to their overall efficiency of power distribution.

We believe, because of the need and opportunity for on-the-farm use of electric vehicles, a special effort should be made to develop a vehicle or vehicles for this market. Most farmers have need for a small service vehicle, perhaps a small pick-up truck, designed for hauling small loads (fuel, feed, produce, etc.) or just running errands around the farmstead. A 50 mile range would be adequate for most tasks and speeds of 40 to 50 mph would rarely be exceeded. Tractors or full sized pick-up trucks usually used for these duties are not only inconvenient but are costly to maintain.

Specialized farming (dairying, poultry, swine, truck farming) offers many possibilities for electric vehicles designed specifically to help automate farming operations. Batteries and electronic controls developed for use in electric passenger and commercial vehicles could substantially enhance the development and use of specialized electric work vehicles on the farm.

We note that the language of H.R. 5470 frequently refers to "urban private passenger vehicles and urban commercial vehicles." Because of the potential for extensive farm and rural use of electric vehicles, we respectfully request that the word "urban" be deleted and that the words "(including farm)" be added after commercial wherever it appears. Thus Sec. 7. (a) (1) should read as follows:

> "(1) for the production, within one year after the date of the enactment of this Act, of significant numbers of passenger and commercial (including farm) vehicles (meeting......"

We also urge that a statement be included in response to the NRECA membership resolution requiring that "studies be undertaken to determine the changes in electric system loads that may result from such development."

Finally we urge ERDA to give special attention to the need for a good public information program, and that "data on electric vehicle safety and operating characteristics" be disseminated as widely as possible via public information media and also to electric utilities.

We very much appreciate this opportunity to present the views of our association in support of H.R. 5470 and to urge you to broaden the legislation and the concept of electric vehicle use to include rural and farm as well as urban.

JUN 10 1975

CARL E. GEIB JR., P.E.

P.O. BOX 4518
2728 PACIFIC AVENUE
STOCKTON CA. 95204

BUS. (209) 463-6667
RES. (209) 478-0272

June 9, 1975

Mr. George E. Brown, Jr., Chairman
Sub-Committee on Enviornment and Atmosphere
Committee on Science and Technology
U. S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D. C. 20515

Re: H.R. 5470 - Electric Vehicle Research, Development and Demonstration Act.

Dear Mr. Brown:

The facts and goals contained in H.R. 5470 are realistic and meaningful to the needs of many of the citizens of our land in the immediate future and in the years to come. You and the other members of the House who authored the Bill are to be commended for overall validity and objectivity stated in the findings, goals and proposed plans contained therein.

I would like to comment specifically to some of the statements in the Bill both to emphasize those points that I believe to be most meaningful and to also supplement the statements with additional facts and data that I have gathered in my development work to date.

Travel patterns of particularly private as well as commercial vehicles are comprised of primarily short trips in urban areas. Such usage is within the capability of electric vehicles of current design with some limitation as to performance plus recognition of the time factor required for battery recharging. These so called short-comings are largely offset by the electric vehicle's total absence of direct emission of air pollutants plus the lower operating energy cost. One must also remember that the gasoline powered automobile is operating at it's lowest efficiency, with the highest pollution emission when performing short trips (following start-up from cooled down state) in urban traffic.

The purpose of the act, to promote substitution of electric vehicles for many internal combustion engine powered vehicles, is a basic need. But the consumer and user must be made aware of and be convinced that much of his individual vehicle transportation requirements can be fulfilled by an electric vehicle in a satisfactory manner. To this end the consumer must not be mislead to believing that it is possible to build in the near future an electric car that will operate and perform like the vehicle he is driving today. Yet, development should be directed toward maintaining current driving techniques, personal comforts and accepted style. And most important, power plant design must be as simple and basic as possible to both hold manufacturing costs to a minimum and make the unit repairable with the minimum of training.

The proposed demonstration timetable goal is attainable utilizing current conventional chassis providing the performance standards and criteria are realistically established for electric vehicle utilization in urban situations that lend themselves to the capabilities of current batteries. I have made extensive tests in which the power requirements of a Volkswagen sedan were determined for an electric configuration conversion. This data demonstrates that the power requirements for acceptable short range transportation can be achieved with currently available components. Tests of a prototype of my design has reaffirmed the validity of the data through over 1300 miles of testing accomplished during routine daily driving.

During the course of this test usage the prototype has been inspected and driven by numerous people. Most of them praise the low noise level, low energy cost and absence of pollution. Performance limitations are questioned to various degrees and become the basis of objections when cost of acquisition is projected. The key here is more exposure to actual vehicle operation and accelerated research and development of componentry directed to manufacturing cost reductions, design simplification and increased operating range.

Enclosed is a copy of a talk I recently presented to a businessmen's group. It contains my thoughts on the present state of the art of development of a practical electric car. The goal and objectives of H.R. 5470 with realistic and sincere guidance can contribute significantly to our future vehicle transportation needs.

Very truly yours,

Carl E. Geib Jr.

Carl E. Geib, Jr.

CEG:nm
Enclosures

CARL E. GEIB JR., P.E.
Consultant

ELECTRIC CAR PAPER 4/20/75

IS THE ELECTRIC CAR A VIABLE SOLUTION FOR GENERAL PURPOSE TRANSPORTATION? NO!!

WILL THE ELECTRIC CAR EVER BE SUITABLE FOR GENERAL TRANSPORTATION? MAYBE -- IN THE DISTANT FUTURE.

WHAT IS THE ELECTRIC CAR GOOD FOR NOW? --Local, light load, short haul use in relatively flat towns.

WHY BOTHER WITH ELECTRIC CARS IF THEY ARE SO LIMITED? -- A large percentage of our driving is local and this creates pollutents at a rapid rate. Fuel economy is poor in local driving. Electric cars produce no pollutents and their electric motors remain efficient during local driving. They do not need to warm up nor do they have chokes.

THE STRONG POINTS OF TODAY'S ELECTRIC CARS ARE: Lack of pollutents and economy of operation.

THE WEAK POINTS OF TODAY'S ELECTRIC CARS ARE: Short range due to battery capacity and poor acceleration and speed characteristics. The range will increase as existing batteries are improved and new types are invented and perfected. The acceleration and speed could be improved today at the cost of battery life and driving range.

There has been much information published about electric cars the last three years. A lot of people have talked about marketing cars, have built prototypes and have sold finished products and positions in line to wait for a product. Most of these electric cars have been new from the ground up. The approach has been to develop a frame, a body and a propulsion system specifically for an electric car. Thus much effort has gone into frames and bodies when what is really needed are batteries, controls and motors. There are many frames and bodies on the highway today that are lightweight, strong, meet standards and are licensed. Why not use these

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4/20/75

frames and bodies as the beginning of electric cars? This relieves the designer of work on frames, body, safety regulation and licensing problems so that he can concentrate on the essential parts of the system - the batteries, controls and motors.

Most of the electric cars that have been proposed and built use series dc motors, directly driving the car without benefit of transmission or clutch. It is necessary to use a series motor in the direct drive in order to get performance. The motor must develop extremely high torque at start and at very low speed and must be capable of running at high speeds. Several methods have been used to control the speed of the vehicle:

1. Steps of resistance in series with the armature with contactors to switch them in and out. This type of control is jerky and wastes a lot of power in the resistors. It is also bulky and expensive.
2. Applying different voltages to the motor by connecting it to different portions of the battery system and/or reconnecting the batteries to different series - parallel arrangements. This method gives jerky operation and unequal discharge of the batteries. It is bulky and expensive, but does not waste power.
3. A combination of #1 and #2 can be used to improve the efficiency of the system and prevent unequal discharge of the batteries.
4. A variable stepless rheostat can be used to eliminate the jerky operation. It can also be used in connection with #2 to get better efficiency and balanced discharge rate. This is bulky and expensive.
5. A solid state SCR or transistor controller is used in the latest designs. This type of controller is efficient, operates smoothly and is relatively light weight and compact. It is expensive.

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4/20/75

Reversing of the vehicle on the above systems is usually done with contactors. However it can be done using solid state devices. Regenerative breaking is not normally available on the above systems. Regenerative breaking requires a shunt field in the motor and regenerative control using contactors or solid state devices.

The shunt type motor seems to have been ignored by most of the electric car developers. It can not be used in a direct drive because of its low starting torque. However the shunt motor has many desirable characteristics:

1. Its output speed and torque can be controlled by varying the shunt field current. In a well-designed motor, the shunt field power can be less than 1/2% of the full load power. This means handling very small amounts of power in the speed control system.
2. The shunt motor can be reversed by merely reversing the polarity of the field.
3. A shunt motor inherently regenerates when overexcited.

Stick-shift automotive transmissions and clutches are readily available and are lightweight, compact, efficient and inexpensive. By combining the shunt motor with the automotive transmission and clutch, we have a system that has adequate performance and is smooth, simple and inexpensive.

The car we have developed started with a standard Volkswagen beetle sedan. We removed the engine and gasoline tank, installed the drive motor, battery boxes, batteries and control system and have a practical electric car for around town driving. Our car uses the standard VW trans-axle, clutch and flywheel and the accelerator pedal. Starting is in low gear and up-shifting is done after the motor is at full speed. This is exactly the way a gasoline powered VW should be driven.

CARL E. GEIB JR., P.E.
Consultant

4/20/75

Speed control between shift points is by a foot-pedal operated rheostat. The car is reversed by using reverse gear of the transmission.

The only difference between the operation of the electric VW and the gasoline VW is in the torque available. It takes the same torque with either drive system to move the car at a given speed. However the gasoline engine system is capable of developing much higher torque and therefore the acceleration is much better.

Our control system consists of two contactors, a resistor and a rheostat. The main contactor connects the motor to the batteries. The auxiliary contactor shorts out the resistor in series with the armature. This resistor cushions initial starting of the motor and reduces the regeneration when coasting. The rheostat controls the shunt field.

Our instrumentation consists of an armature ammeter and a battery voltmeter.

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Consultant

Battery Systems

Most of the present electric cars are powered by lead-acid batteries or one of their derivatives. These batteries are fairly heavy and bulky and have a very limited output. We are using golf cart batteries in our vehicle because they appear to give the most usable ampere hours per pound and per dollar. The penalty for using this type of battery is the expected life.

A number of approaches have been proposed to make the lead-acid battery more practical. Many vehicles have been designed so that the entire battery pack can be removed and exchanged in just a minute or so. This approach is practical where a vehicle operates on many trips out of a central location. As the batteries in the vehicle are discharged, they can be rapidly removed, a fresh set installed and the vehicle is back on the road while the other batteries are being charged.

It has been suggested that the same approach be used in private cars and exchanging stations would be used instead of filling stations. As your batteries become discharged, you would go to the recharging station and exchange battery packs. Some of the problems involved here are:

1. How does the recharging station operator charge for an exchange set of batteries?
2. How does he know you haven't given him a set that is almost worn out?
3. How do you know that he hasn't given you a worn out set?

Another solution to the battery problem will be to have the battery charger as part of the vehicle and have battery recharging plug-ins coin operated like parking meters located in many parking areas around town. When you go to the shopping center, you could plug in your vehicle, deposit 5 or 10 cents in the slot and get a partial recharge while shopping. Employers could provide metered charging stations for employees and bill them monthly for the power used.

By providing easy means of recharging the batteries, we eliminate part of the need for a long range car.

Fish Enterprises,
Minneapolis, Minn., July 3, 1975.

Hon. Mike McCormack,
Chairman, Subcommittee on Energy Research, Development, and Demonstration, Committee on Science and Technology, U.S. House of Representatives, Washington, D.C.

Dear Mr. McCormack: Thank you for your letter regarding testimony for the hearings on the Electric Vehicle Research, Development and Demonstration Act of 1975 (H.R. 5470), and the enclosed copy of the bill. As I was unable to attend, I would like to receive a copy of the oral and written testimony, when it is available.

May I call your attention to the use of Flywheels for use in electric vehicles for energy storage. These are far surperior batteries in terms of lifetime, power availability discharge depth etc. This is particularly true when modern composite materials and designs are utilised. Using a flywheel as a buffer between the engine and the transmission can reduce the engine size by half even with conventional vehicles. Flywheel technology has only lacked the resources in manpower and finances to be developed.

For this reason may I recommend that your bill H.R. 5470 be amended to specifically include "flywheels" in addition to batteries in Sec. 4(1) and sec. 6(1).

The following references go into detail into the potentials and uses of flywheels:

David W. Rabenhorst, "Electric Vehicle Without Batteries," 16th Annual Technical Meeting, Institute of Environmental Sciences, Boston April 12, 1970.

G. L. Dugger, A. Brandt, J. F. George, L. L. Perini, D. W. Rabenhorst, T. R. Small, and R. O. Weiss, "Heat-Engine/Mechanical-Energy-Storage Hybrid Propulsion Systems for Vehicles-Final Report" APL/JHU Report CP 011 March 1972.

R. R. Gilbert, J. R. Harvey, G. E. Helier, and L. J. Lawson "Flywheel Feasibility Study and Demonstration-Final Report" Lockheed Missiles and Space Company Report LMSC-D007915 April 30, 1971.

R. F. Post & S. F. Post "Flywheels" Scientific American Vol 229, 17 December 1973.

If these references and discussion of flywheels have not yet been submitted to your committee, you are welcome to include them in your records.

I would appreciate being included on your mailing list for your energy newsletter, and any other letters and notices that you distribute concerning energy and related news and legislation.

We would encourage you and others in Congress to provide strong farsighted leadership in developing renewable energy sources. When we have the capability of developing solar and wind energy to provide all our energy requirements at competitive costs, it is discouraging to see all the emphasis being put on fossil fuels and nuclear fission. In facing the growing fuel shortages over the next decades we need strong measures now. I would encourage you to press for strong conservation measures on automobiles and in buildings. We also need strong land reclamation laws to cover coal mining, e.g. similar to what is already in force in Europe.

Considering the dangers of terrorism, environmental pollution catastrophic accidents, limited fuel supply, and the dangers of radiation, I for one would vote for a complete moratorium on further development of nuclear fission power plants and weaponry, and that all these funds be put toward solar energy. There is growing support on all these issues in the area.

We would like to see some cooperation and effective leadership in congress on these issues, rather than pettiness and weakness in the face of apparent political pressures and local interests, and the automobile, and energy companies. Let us know where we can be of assistance.

Thank you for your help in keeping us up to date on your legislation.

Sincerely yours.

David Hagen.

EXXON ENTERPRISES INC.

1251 AVENUE OF THE AMERICAS NEW YORK N Y 10020

R P Hamlen
Manager
Advanced Battery Project

July 9, 1975

Honorable Mike McCormack, Chairman
Subcommittee on Energy Research Development,
and Demonstration
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. McCormack:

Thank you for your invitation to comment on the Electric Vehicle Research, Development, and Demonstration Act of 1975 (H.R. 5470). I have discussed the proposed bill with others within Exxon having an interest in batteries and electric vehicles, and our comments follow.

As a result of the continuing trend toward an increasingly electricity-based energy system in the United States, we recognize the need for a practical electric vehicle of general utility to the public. We feel that in the future this could be one of the viable alternatives for fulfilling our transportation needs. This would also provide us with an extra degree of flexibility with regard to utilization of liquid fuels. We support the idea of a vehicle demonstration program, but think that the timing of the bill should be changed somewhat. One of the major hurdles to be overcome in developing better electric cars is the development of a higher energy density battery. Therefore we feel that less emphasis should be placed on the near-term support of vehicles employing current lead/acid batteries, but that support, increasing with time, should be provided for building and buying improved vehicles using new high performance batteries of an experimental nature. We think that the overall time span should be increased to at least 6 years to allow for these developments.

As energy storage technology is developed, we feel that an electric vehicle demonstration program will become increasingly more valuable for obtaining public acceptance of a passenger vehicle of the type which could be used as a second car. However, we agree with those who testified before the Committee to the effect that better batteries are needed before electric vehicles become feasible for wide-spread use. There already exist a limited number of applications where vehicles with a limited range are practical, such as in multi-stop urban delivery service. But it is our feeling that a vehicle having a range of at least 100 miles is necessary to achieve general acceptance by the public. This requires the development of a battery having an energy density of at least 40 to 50 watt-hours per pound, or about three times that of existing lead/acid batteries. Such a battery must also have a reasonable cost and life-time.

As part of our testing and development program for electric vehicles, we have attempted, using two electric vans, to establish the use pattern of a lead/acid powered vehicle by typical "consumers" using it as a second car. We found that, although the vehicles employed have a range of 30 to 40 miles under optimum conditions, the average driver would tend to use it for trips of 15 miles or less in order to ensure a sufficient reserve to return home. It is for this reason that we feel that a range of about 100 miles is necessary, in order to allow for this reserve, even though the average local trip is appreciably less than 100 miles. Although it is possible to extend the range of lead/acid powered vehicles by adding more batteries, the weight of batteries becomes prohibitive before a practical range of 100 miles is achieved.

We have also become aware that there is a need for a more efficient electric motor-control system combination, in order to utilize the battery energy with minimum energy losses.

Our work makes us keenly aware of the need for a vehicle demonstration program, such as presented in House Bill 5470, to determine the best alternatives and to demonstrate feasibility to potential users. It is obvious that a considerable amount of thought went into planning and laying out the background for the bill. However, we feel that its desirability would be enhanced by placing the initial emphasis on developing vehicle technology, especially in the motor and control area, with a gradually increasing emphasis with time on the demonstration phase.

Because of the magnitudes of the scientific and engineering problems which must be overcome in developing an improved battery, as well as the long time required to demonstrate significant life capability in a new battery system, we feel that the proposed three-year time span for funding should be expanded to 6 or 7 years. This would provide:

1. Time for a continuing major effort aimed at developing better batteries, such as is being conducted by private industry and at the Argonne National Laboratory.

2. An initial period during which a limited number of electric vehicles would be demonstrated in appropriate limited range applications using lead/acid batteries, with emphasis on motor and control system development, to establish a basis for future comparisons.

3. A government sponsored demonstration program in the area of new batteries, controls, and design concepts as they become available.

4. A major vehicle demonstration program nearer to the end of the program employing the best technologies available.

A possible undesirable effect of an immediate major demonstration program is that, because of the severely limited speed and range of any practically-sized passenger vehicle built with available technology, it may well be that the reaction of the typical users could be negative rather than positive. This would complicate the public acceptance problem at that time in the future when improved batteries become available.

In summary, we agree with the goal of developing suitable electric vehicles for both commercial and private use, but feel that the major hurdle at present is the development of a suitable high energy density battery. We believe that the government could offer incentives to private industry, through an electric vehicle demonstration program, to speed the development of batteries, control systems, and other components, by providing a fair basis for evaluation, and ultimately to speed the introduction of an electric vehicle.

Very truly yours,
Robert P. Hamlen

Robert P. Hamlen
Manager, Advanced Battery Project

RPH/mmm

news
FROM COPPER DEVELOPMENT ASSOCIATION INC.
405 Lexington Avenue • New York, New York 10017 • (212) 953-7300

DATA SHEET:
COPPER ELECTRIC TOWN CAR

FOR ADDITIONAL INFORMATION
New York - Estes Jones (212)953-7326
Birmingham,Mich. - Keith Carlson
(313)J06-7907

The Copper Electric Town Car is a front wheel-drive vehicle with all components concentrated under the hood. The specially-wound motor has a separately excited field. The motor is mounted on a transfer case which contains a non-lubricated, lightweight durable belt drive to the spiral-bevel gear differential. Power is transmitted from the differential to the wheels by shafts with sliding, cross-type universal joints at the inner ends and Rzeppa constant-speed universal joints at the outer ends.

The electric motor and associated control system are designed to minimize electrical losses while providing the necessary performance characteristics. The design eliminates the need for any type of mechanical speed changing, thus eliminating the weight of a manual or automatic transmission. Both motor and control system are described in more detail in the accompanying SAE Paper No. 750470.

The spiral-bevel-gear differential used is mechanically more efficient than the hypoid type typically used on American automobiles.

Front wheel suspension is the McPherson Strut type used on many conventional automobiles. Independent rear suspension units use torsion bar springing.

Minimizing Air Resistance

Since the aerodynamic drag on an automobile at 40 mph is approximately 50 percent of the total drag, every effort was made to minimize air resistance. These include: minimum frontal area, body shape, smooth underpan, no protrusions such as door handles. All windows and windshield flush with the car's outer surface and the flush hatch concealing the windshield wiper.

Minimizing Mechanical Friction

In addition to the spiral-bevel-gear differential and the belt drive from motor to differential which reduces mechanical friction, the Copper Electric Town Car uses radial-ply tires to reduce rolling resistance.

Batteries

The 18, 6-volt batteries which power the Copper Electric Town Car are commercially-available units of the lead-acid type. They were selected for the optimum combination of weight, energy content, and discharge-charge cycle capability. The batteries are housed in the central tunnel or backbone of the car. As shown in accompanying photo, they are easily slid out the rear of the car for servicing or replacement.

The batteries are fitted with special caps containing a catalytic element which causes the hydrogen and oxygen evolved during charging to recombine into water which drains back into the cells. The special catalytic cell caps thus increase the interval time for the addition of water to the cells.

Structure

Unitized construction is used for the Copper Electric Town Car. There is no separate frame as with some automobiles. The main structural member is the large steel box backbone which houses the batteries and serves also as a safety feature for passengers. All body panels are steel. Every effort was made to keep the structure as light as possible to reduce weight and thus reduce energy consumption without resorting to exotic or expensive materials and techniques.

Brake System

Another noteworthy feature in the design of the car is the use of copper alloys in the braking system. Special high strength corrosion-resistant copper alloy tubing is used for the hydraulic brake lines. Copper alloy brake drums are used at all four wheels in the self energizing brake system. Copper alloy drums, because of their thermal conductivity, reduce fade, provide increased lining life, and increase the horsepower absorption of the brake system.

COPPER ELECTRIC TOWN CAR SPECIFICATIONS

Vehicle

Length, Overall	145 inches
Wheelbase	80 inches
Width, Overall	60 inches
Height, loaded	54.5 inches
Ground clearance	8 inches
Weight, with batteries	2952 pounds
Weight, with batteries and full load	3302 pounds
Battery weight	1206 pounds
Turning circle, curb-to-curb	28 feet
Tread	Front, 50.2 inches; Rear 51 inches
Tire size	AR 70-13

Performance

Speed, maximum, mph	in excess of 55 mph
Range, at steady 40 mph	120 miles
Range, 2 stop/mile suburban cycle reading 35 mph	75 miles
Acceleration 0-30 mph	11.8 seconds

Electrical

Operating voltage	108/54
Number of batteries	18
Motor hp	41 maximum
Motor diameter	12-3/4 inches
Motor, rpm, maximum	5500 rpm
Charging voltage	54
Charging current	20 amp,maximum
Normal charge time	8 hours

Tech/Ops

Advanced Technology Division
20 South Avenue
Burlington, Massachusetts 01803
Telephone (617) 272-2000

27 June 1975

Mr. Mike McCormack
Chairman Subcommittee on Energy
Research, Development, and Demonstration
Committee on Science and Technology
U.S. House of Representatives
Suite 2321, Rayburn House Office Building
Washington, D. C. 20515

Dear Mr. McCormack:

Thank you for your invitation to comment on H.R. 5470. I would like the following statement to be included in the hearing record.

The intent of H.R. 5470 is to provide impetus to the establishment of an electric alternative to the use of the internal combustion engine by the commuting public. Such a systems impetus is useful principally in situations where many sub-elements of the system need extensive concurrent development. In the case of an electric vehicle, this is not so. The state-of-the-art in electric motors, controls, and their transmission systems is very well established and could with relatively little further research be able to function satisfactorily in electric vehicles. The severe weakness in the successful development of electric vehicles is the storage system. A truly viable vehicle with speeds and costs competitive with current automobiles is not possible with the lead-acid battery or its reasonable alternatives. Neither is it likely to be competitive until the power to weight ratio is improved by at least an order of magnitude. By encouraging an overall systems development, it is necessarily going to force designers of the other componentry to optimize their subsystems to coincide with the characteristics of a lead-acid battery. This optimization may be in conflict with the characteristics of the future high density power sources which are anticipated in the future. It is suggested that early studies be made which project the possible range of characteristics likely to be encountered from future batteries so that manufacturers of control systems such as ourselves may not be induced to over-develop controls for what is ultimately the wrong power storage system.

The recommendation therefore is that the bill be modified to emphasize the special need for most of the effort to be placed in research, development, and demonstration of high density storage systems, and the sub-elements which are directly affected by battery design.

I thank you for the opportunity to have these comments placed in the records and would be pleased to provide any further details that you require.

Sincerely,

J. F. Harvey

J. F. Harvey
Vice President and
General Manager

JFH/sk

SGL BATTERIES MANUFACTURING CO.
A subsidiary of SGL INDUSTRIES, INC.

14650 DEQUINDRE
DETROIT, MICHIGAN 48212
(313) 868-6410

July 1, 1975

JUL 2 REC'D

The Honorable Mike McCormack, Chairman
Subcommittee on Energy Research,
Development, and Demonstration
U.S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. McCormack:

Thank you for your recent correspondence regarding HR #5470, which you are sponsoring. Please consider this a formal request to include the following in the hearing record.

Our company, SGL Batteries Mfg. Co., is a prime manufacturer of lead-acid storage batteries for use in many and varied battery-powered electric vehicles. I have been directly involved in designing, for particular application, special-sized, high-capacity, relatively compact batteries. Some of the subject vehicles include golf cars, floor scrubbers and sweepers, personnel carriers, and in-plant material vehicles, as well as automobiles and small van-type trucks.

My contacts in the above fields have afforded valuable, educational background for basic knowledge in the tremendous potential in conservation; pollution-control; promoting a more favorable balance-of-trade position; diverting our dependence upon a commodity with a foreseeable availability limit; as well as one which is controlled by foreign sources; and reversing the inflationary trend of ever-increasing fuel costs. It should be borne in mind that electric-powered street vehicles have been operating successfully commercially and are proven, practical-performance units in large fleets throughout Europe. Some of the subject applications are route trucks, second family autos, and large buses. It is my considered opinion that the comparatively much higher cost of gasoline, until recently, was responsible, to a great degree, for their apparent head start.

I respectively urge that positive action on HR #5470 be taken and that the Act, once passed, be implemented fully with all expediency.

Very truly yours,

SGL BATTERIES MANUFACTURING CO.

R. J. Hollander
President

RJH/smp

MEMBERS OF BATTERY COUNCIL INTERNATIONAL
INDEPENDENT BATTERY MANUFACTURERS ASSOCIATION

STATEMENT FROM DR. K. V. KORDESCH
IN SUPPORT OF H. R. 5470
TO SUBCOMMITTEE ON ENERGY RESEARCH DEVELOPMENT AND DEMONSTRATION

JULY 1, 1975

I am Dr. Karl V. Kordesch, Corporate Research Fellow, with Union Carbide Corporation. As an individual who devoted most of his scientific career to the advance of electrochemistry and in particular to the improvements of battery systems, I wish to emphasize the importance of legislation as outlined in H. R. 5470. However, for reasons stated later, neither myself or Union Carbide is presently working on fuel cell technology or electric vehicles.

Considerable technological progress in the field of new and unconventional electric power sources suitable for electric automobiles is urgently needed.

I refer particularly to Section 6: "Research and Development, (1) concerning energy storage technology, including batteries and their potential for convenient recharging."

Fuel cells must be considered the ultimately successful type of mobile electric power source with properties closely approaching the present gasoline powered vehicles (Ref. 1).

Fuel cells have made it possible to supply the electrical requirements for the manned space capsules of the Apollo program leading to the successful moon landings.

Fuel cells have been built for various projects connected with Government agencies. For many years a large program, sponsored by the utilities industry is in progress, with the intention to extend fuel cell power units from several kilowatts to megawatt size.

A national investment of some hundreds of millions of dollars has been made over the last 15 years (and is continued) for establishing the technology of fuel cells, a relatively small part of it was spent for electric vehicle battery development; actually the conclusions which were made at that time (1967) in the early stages of fuel cell system developments acted as a barrier for further work (Ref. 2).

I have myself, as a personal project continued the study of fuel cell power plants for automobiles and have demonstrated that the technological difficulties can be satisfactorily surmounted if one relaxes the requirements for a very powerful engine capable of extreme acceleration and speed, as it was customarily assumed to be of a necessity in 1967. Also battery performance, life and cost expectancies have been drastically changed by introducing the concept of a fuel-cell and secondary battery (hybrid) power system operating with air (instead of oxygen) at ambient temperatures.

In the following, the abstract of one of my 1971 publications (Ref. 3) is reprinted. A picture of the car is shown in Figure 1.

HYDROGEN-AIR/LEAD BATTERY HYBRID SYSTEM FOR VEHICLE PROPULSION

The high energy density of a fuel cell battery and the peak current capability of a secondary battery are combined in the power plant of an electric car. The four-seat vehicle weighs 2000 lb and is powered by a 7 kW (20 kW peak) d-c motor. The 6 kW hydrogen-air fuel cell battery is connected in parallel with a 4 kWhr lead battery (84V); 660 ft^3 of hydrogen are stored in six lightweight cylinders (180 lb total weight) equivalent to 33 kWhr of actually available electric energy. The design of the fuel cell battery was aimed at very long life expectancy on intermittent duty, fast automatic starting and shutdown, reliable safety features, and use of available commercial accessories. The operation of the car is not more difficult than driving a conventional auto; the range is over 200 miles. The refilling of the hydrogen cylinders takes only a few minutes from a 2000 psig supply. The acceleration is similar to that of a small car with a combustion engine. Top speed is 55 mph.

In a second publication the experiences with that car after one year operation in city traffic was reported (Ref. 4). Maintenance needs, cost of fuel , reliability and life expectancy questions were discussed and found to be within existing technology range. Improvements were considered to be required in power density and battery production cost (mainly catalyst cost).

It should be stressed that the 1971 conclusions still could not result in decisions to start developing electric vehicle fuel cell power plants. The near term alternative was a sufficiently clean internal combustion engine and the need for a battery operated automobile was not a convincing argument, even with a range surpassing the lead acid powered car by a factor of three to five. The high investment cost for the development of such new systems was simply prohibitive in lieu of the possible gains calculated.

In the meantime, the energy crisis made its official debut and the electric vehicle situation was re-evaluated.

Besides of the arguments, valid for battery powered cars, namely their quietness, cleanliness and low maintenance, fuel cell operated vehicles in conjunction with a secondary battery for peak power provide the following additional features:

- The operating range extends to over 200 miles before simple refueling is required. "Fuels" have a high energy density (e. g., 1000 Wh/lb).
- No electric recharging; the filling of fuel tanks, takes only minutes. No special power lines or chargers are needed.
- Long life expectancy. 5000 operating hours correspond to about 150,000 miles city driving.
- Increased power: normal accelerations and hill climbing properties if the "hybrid" concept is used.
- High fuel efficiency; 50% conversion efficiency versus the 15 to 20% of a combustion engine or the rechargeable electric car.

The last point is of highest importance from the viewpoint of energy savings. To understand it, a short excursion into basic electrochemistry must be made (Ref. 5).

A fuel cell is a galvanic element consisting of positive and negative (porous) electrodes to which gaseous or liquid chemicals are supplied in a continuous fashion (contrary to conventional batteries which contain all the active chemical substances within their plates). The most practical gaseous oxidizing chemical is air. Space fuel cells used oxygen. "Fuels" may be gaseous, like hydrogen, or liquid like methyl alcohol. The reaction product must be continuously removed to keep the battery invariant (in a hydrogen-air battery, water is the reaction product and is evaporated).

Since a fuel cell is not a heat engine, its efficiency is not restricted by Carnot's law and can be theoretically near 100%, practically around 50-60%. Large (heat) power plants can operate around 40%, small engines show seldom more than 20% conversion efficiency.

The efficiency of a fuel cell is not size related either. The capacity of a fuel cell power plant depends only on the size of its fuel tank, in that sense it performs like a generator. It uses fuel only when power is drawn. A rechargeable battery (lead acid, nickel cadmium, or more recently sodium-sulfur, a high temperature system) needs recharging and is dependent on the electric power plant as energy supplier (with at best 40% efficiency) needs distribution lines, increases charge and discharge losses. The over-all efficiency is therefore not better than that of a gasoline engine. Of course, if the pipe line gas for the power plant or the hydrogen for the fuel cell is derived from coal by steam conversion, the efficiency of this process must be considered too; still, the advantage of the fuel cell as a primary cell persists. There is also no self discharge if the fuel cell system is shut down. Starting or cycling problems are minimal compared with rechargeable cells or high temperature cel

With all these advantages it is hard to comprehend that fuel cells have not already been developed for automobiles. The big obstacle is cost. Catalyst cost, mainly. Most fuel cells (all space systems) use noble metals as catalysts.

Fuel cells for power plant or load leveling applications can be allowed about $150 to 500, depending on applications, for the cost of one kW installed power. This number is now acceptable since the energy price is increased considerably, fuel cell developers believe they can produce units at those kW prices. An automobile should have an (average) 20 kW power plant to provide an acceptable performance (competing with gasoline) in the city. In a hybrid system the secondary battery will provide the peak power (50 kW) and be recharged from the fuel cell system.

These figures set the cost of an automobile power plant at a (presently calculated) minimum of $3000. Automobile manufacturers supposedly require a fuel cell system cost of $20 to $50 per kW before they become interested. It is questionable if any nonconventional system we know today could be produced at such a low cost; but we may also consider that an automobile system does not have to operate 40, 000 hours continuously, as required by the power plant designers. Automobile systems can be designed more like the small, volume efficient, light weight space systems which are existing. To replace precious metal catalysts with non-noble metal high performance catalyst is possible, as we know today, from alkaline fuel cell systems being produced in Germany (Ref. 6).

The outlook for automobile fuel cell system is not a question of financing many small dispersed efforts; for its success it is essential that a concerted large effort is made. In my opinion only an expenditure of the space fuel cell magnitude can push the existing technology far enough to become applicable for electric automobiles. In view of the possible advantages over all other presently conceivable systems, it is a relatively low price to pay.

Future energy scenarios picture a hydrogen fuel economy based on coal conversion or nuclear power production (plus electrolysis of water). Instead of hydrogen we may set other derived simple chemicals (methanol, ammonia, even synthetic auto-fuels). Fuel cells can be principally adopted to each fuel, if internal conversion is added, even to hydrocarbons. If we picture our future factories to operate on a gas pipe - (not electric power line-) distribution system, then it is only a logical step to try to operate fuel cell electric automobiles on the same fuel. The use of rechargeable batteries, lead acid cells, or any other kind would certainly help in certain load leveling (use of off peak power) schemes, but this concept would be wasteful if primary fuel cells would first generate this electricity in local (small) plants (Ref. 7).

REFERENCES

(1) K. V. Kordesch, Power Sources for Electric Vehicles, Chapter 7, pp. 339-443, Modern Aspects of Electrochemistry, Vol. 10, J. O'M. Bockris, ed., Plenum Publishing Co., N.Y. 1975

(2) B. J. Crowe, Fuel Cells, A Technology Survey, NASA-SP-5115 Contract NASW-2173, Technology Utilization Office, Washington, D.C. 1

(3) K. V. Kordesch, Journal of Electrochem. Soc., 118, pp. 812-817 (1971)

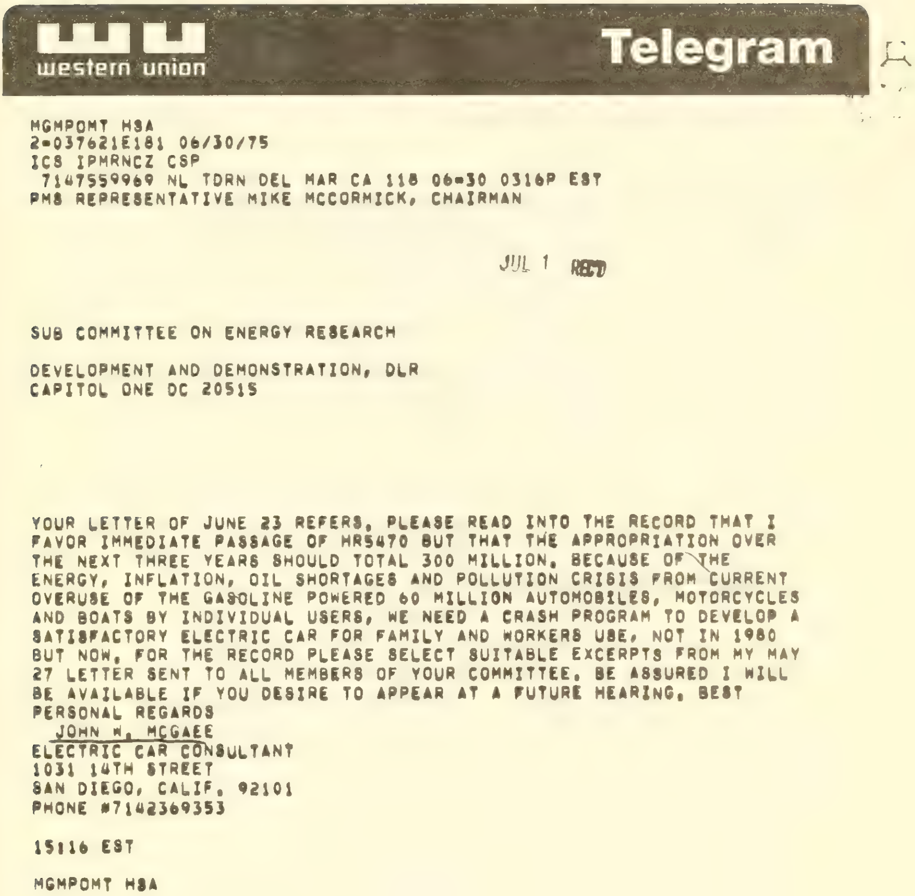
(4) K. V. Kordesch, City Car with H_2-Air Fuel Cell/Lead Battery (one year operating experiences) 1971 Intersociety Energy Conversion Engineering Conf. Proceedings, paper No. 719015, Soc. of Automotive Engr., Inc.

(5) J. O'M. Bockris, S. Srinivasan, Fuel Cells, Their Electrochemistry McGraw Hill Book Co., New York, 1969.

(6) A. Michel and W. Frie, paper no. 7452, 3rd International Electric Vehicle Symposium, Washington, D.C, 1974.

(7) K. V. Kordesch, Electric Vehicles, Chapter in, Batteries, Vol. 2 K. V. Kordesch, ed., Marcel Dekker, Inc., N.Y. (in processing)

Fig. 1: Four Passenger Car, operated on a Hydrogen-Air/Lead-Battery. The fuel cell battery is mounted in the rear, the lead battery under the hood.



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PMS REPRESENTATIVE MIKE MCCORMICK, CHAIRMAN

JUL 1 RECD

SUB COMMITTEE ON ENERGY RESEARCH

DEVELOPMENT AND DEMONSTRATION, DLR
CAPITOL ONE DC 20515

YOUR LETTER OF JUNE 23 REFERS, PLEASE READ INTO THE RECORD THAT I FAVOR IMMEDIATE PASSAGE OF HR5470 BUT THAT THE APPROPRIATION OVER THE NEXT THREE YEARS SHOULD TOTAL 300 MILLION. BECAUSE OF THE ENERGY, INFLATION, OIL SHORTAGES AND POLLUTION CRISIS FROM CURRENT OVERUSE OF THE GASOLINE POWERED 60 MILLION AUTOMOBILES, MOTORCYCLES AND BOATS BY INDIVIDUAL USERS, WE NEED A CRASH PROGRAM TO DEVELOP A SATISFACTORY ELECTRIC CAR FOR FAMILY AND WORKERS USE, NOT IN 1980 BUT NOW. FOR THE RECORD PLEASE SELECT SUITABLE EXCERPTS FROM MY MAY 27 LETTER SENT TO ALL MEMBERS OF YOUR COMMITTEE. BE ASSURED I WILL BE AVAILABLE IF YOU DESIRE TO APPEAR AT A FUTURE HEARING. BEST PERSONAL REGARDS

JOHN W. MCGAEE
ELECTRIC CAR CONSULTANT
1031 14TH STREET
SAN DIEGO, CALIF. 92101
PHONE #7142369353

15116 EST

MGMPOMT HSA

Statement for the Record

Subcommittee on Energy Research, Development & Demonstration
Committee on Science & Technology
by
Precision Products Company, Division of Vantage Boats
7313 E. Boudinot Drive, Springfield, Virginia 22150

We are of the opinion that the Government and private employers should encourage the use of Electric Autos by facilitating charging employees cars at their places of work.

By charging an Electric Car both at home and at work the range is doubled which increases dramatically the number of commuters who could use the vehicles.

To the extent that funds would be needed to encourage the GSA and others to cooperate, the funds could be provided for in the ELECTRIC VEHICLE RESEARCH, DEVELOPMENT AND DEMONSTRATION ACT.

Charles E. Minarik, Jr.
Precision Products Co.
Springfield, Virginia
August 21, 1975

Electric Auto Association

~~1373 Dentwood Drive, San Jose, California~~ 95118

May 30, 1975

O.E.T.

Mr. Olin E. Teague, Chairman
Committee on Science and Technology
U. S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D. C. 20515

My Dear Mr. Teague:

Please have the enclosed statement read at the hearings on "Electric Vehicle Research, Development, and Demonstration Act of 1975" H.R. 5470, which are understood to be on June 3,4&5.

For your information the objects and purposes of the Association are:

to act as a clearing house of information for the members, other organizations and the public on the developments in the electric auto technology at home and abroad.

to encourage experimentation in building of electric autos by individual members of the Association.

to promote and organize public exhibits of such vehicles for the purpose of informing the general public about the progress on electric autos.

to publish technical material helpful in construction of electric autos.

Respectfully yours,

John B. Newell, President
Electric Auto Association
1249 Lane St. Belmont, Ca.
94002

May 30,1975

REGARDING H. R. 5470 et al "ELECTRIC VEHICLE

RESEARCH, DEVELOPMENT, AND DEMONSTRATION ACT OF 1975"

The Electric Auto Association recommends the electric car as one of the best partial answers to the following national problems:
  Shortage of energy resources.
  Contamination of the environment.
  Unemployment.
  Inflation.

First let us make it crystal clear that we are not talking about a theoretical type of car of the future. For some evidence see Enclosure #1, pictures of several dozen existing, high performance cars. The Association now has an electric vehicle which can demonstrate and is demonstrating a tremendous savings of fossil fuels in urban traffic. It is both dangerous and unwise to postpone the advancement of improved cars any longer, for example a few years or a decade. We have an urban electric car today. The batteries are adequate and will improve as the demand improves. The capability to produce electric cars has been demonstrated. The electric supply and support systems are standing by already, and are adequate for the immediate future. Their efficiencies will even improve with car utilization. In the extreme case the Association has demonstrated that a windmill at home can supply a comuter's vehicle with needed energy. In a more normal situation the overall fuel consumption is being demonstrated to be ten times better than the best internal combustion or steam vehicle.

With such a potential vehicle, why should we continue to stunt our industrial growth by fuel shortages and let our well being become seriously threatened? Urban electric cars can provide one real, practical, and benefitial avenue of escape from energy exhaustion, contamination, unemployment, and some inflation. Where else, under today's conditions, can we accomplish so much energy conservation so rapidly? Such a vehicle would be saleable abroad.

The Act is urgently requested as proposed. Any data required to substantiate the above will be provided if requested.

FRANK E MOSS UTAH CHAIRMAN
STUART SYMINGTON MO
JOHN C STENNIS MISS
HOWARD W CANNON NEV
WENDELL H FORD KY
DALE BUMPERS ARK
BARRY GOLDWATER ARIZ
PETE V DOMENICI N MEX
PAUL LAXALT NEV
JAKE GARN UTAH
ROBERT F ALLNUTT STAFF DIRECTOR

United States Senate
COMMITTEE ON
AERONAUTICAL AND SPACE SCIENCES
WASHINGTON, D.C. 20510

June 10, 1975

The Honorable Mike McCormack
Chairman
Subcommittee on Energy Research,
Development and Demonstration
Committee on Science and Technology
U. S. House of Representatives
Washington, D. C. 20515

Dear Mr. Chairman:

I am pleased to submit this statement for the record in support of the Electric Vehicle Research, Development, and Demonstration Act of 1975.

Last year, Americans faced the reality that gasoline is a limited fuel and that shortages can occur even in the United States. Americans depend very heavily on automobiles for transportation -- statistics for 1972 indicated that passenger automobiles traveled over 980 billion vehicle miles. The flexibility and convenience of the automobile, as much as anything else, have made it the basic form of transportation in this country. Surveys of the large numbers of automobile trips that the Nation's 118 million licensed drivers make indicate that over 50 percent of these trips were for a distance of less than five miles, and 70 percent were for less than ten miles. Further investigation shows that of all passenger automobile trips, nearly 37 percent are made in earning a living, including over 35 percent traveling to and from work or related to work. In other words, automobile trips are typically very short.

Yet other studies show that the fuel economy achieved by motor vehicles on short trips is poor, a fact that has not escaped the attention of any urban driver. I think that this situation demands that we look at other sources of power for automobiles that would be more efficient on short haul trips. An excellent candidate is electricity.

Electric cars offer many advantages over our current automobiles for urban driving, especially for short trips within the city. But electric cars have not been developed for widespread use because of the limitations imposed by today's batteries. The problem in a nutshell is we need an electric car battery that has sufficient energy storage capacity, power delivery capability, and lifetime to give the electric car the same range and performance as the conventional automobile.

However, the signs are hopeful because there are advanced battery systems which appear promising. It is expected that these batteries will have sufficient specific energies and specific power to permit the design and construction of electric vehicles with excellent acceleration capabilities and a range of about 200 miles between recharges.

An electric car with this capability will certainly be suitable for driving in the city. Advantages of such electric cars would include reduced air pollution because they can be recharged from commercial electric sources resulting in reduced pollution within cities. For instance, one can envision fleets of electric cars being rented to commuters at urban distribution points along major subway or bus routes. At night these electric rental cars would be charged up for the next day's rush hour demand.

However, more power would have to be generated at the central power station. This would result in more air pollution at that location, but it would probably be easier to control the pollutants from several smoke stacks in a city than the pollutants from the tailpipes of the thousands of cars in that city. A spokesman for Chicago's Commonwealth Edison Company estimated that even without nuclear reactors, his company could recharge about 500,000 electric vehicles at the low-load night period without significant change in smoke stack emissions.

We can also anticipate large savings in petroleum because many electric utilities use coal and a growing number of utilities use nuclear power for generating electricity. Recharging electric cars from commercial electric sources would also result in a better utilization of our utilities during hours when off-peak power is readily available. A National Academy of Sciences report indicates that as nuclear power generation assumes an increasing importance in the total energy generation spectrum, the use of off-peak capacity for recharging the batteries of electric vehicles would offer an even more significant advantage with respect to efficient use of plant investment, as well as a reduction of operating costs.

Another advantage of electric cars is that they are mechanically simpler than cars having internal combustion engines. They can have a lower initial cost, less maintenance cost, more trouble-free operation, and longer life. Some small electric cars coming on the market are selling for less than $2,700 (f.o.b.) for a two-seater. As for maintenance and reliability, the electric car can have only a battery, electric motor and voltage regulator to power it. The average automobile today has a battery, voltage regulator and several electric motors (heater fan, windshield wiper, windshield washer) besides its gasoline engine and associated equipment. Similarly, the emergence of the electric car is ushering in a new era of automobile longevity. While most electric cars in constant service will need to have their batteries changed about every two or three years, at an approximate cost of $300, the drive train of these vehicles is good to a minimum of 100,000 miles and perhaps as long as 400,000 miles. So an electric car may outlast an internal combustion (engined) car by a considerable margin.

Overall, the operating characteristics of electric cars make them very conducive to city operation in that (1) they add almost no pollution -- what pollution there is comes from the electric generating plant and can be controlled; (2) they have a very low noise level, merely a hum even in acceleration; (3) they use no power when standing still; and (4) they have very simple controls for operation.

I believe that we must find alternatives to the gasoline-powered automobile in the very near future. And one area worthy of serious investigation is the electric car. I have introduced S. 1632, a bill that is similar to the Electric Vehicle Research, Development, and Demonstration Act of 1975. These bills will assist the American electric car industry in producing a practical car for urban transportation. Simultaneously, this bill would create jobs badly needed for Americans and it would lead to a reduction in the outflow of American petrodollars.

Sincerely,

Ted Moss

Frank E. Moss
Chairman

FEM:par

GES GESELLSCHAFT FÜR ELEKTRISCHEN STRASSENVERKEHR, M.B.H.,
DÜSSELDORF, GERMANY,
September 22, 1975.

Re Electric Vehicle Research, Development, and Demonstration Act of 1975.

Hon. MIKE MCCORMACK,
U.S. House of Representatives,
Washington, D.C., U.S.A.

DEAR SIR: The Electric Vehicle Council, to which my company belongs as a corresponding member, informed me of the very important bill you committed to the Congress of the U.S.A.

My American friends encouraged me to make some comments which might be important for your further considerations.

GES is a subsidiary of Rheinisch-Westfälisches Elektrizitätswerk Aktiengesellschaft (RWE), the largest electricity supply company in the Federal Republic of Germany.

In 1970 we started a program, nearly identical to the one proposed in your bill, together with more than 20 manufacturers including such important companies as Robert Bosch GmbH., Siemens AG, Volkswagen, AG, Daimler-Benz AG, Maschinenfabrik Augsburg-Nürnberg AG, Varta Batterie AG, etc.

The program is sponsored by different government authorities but mainly financed on private basis. As far as we know this was the first time in the world that an integration was undertaken of all the industrial groups from the automobile industry to the electric industry to the electricity supplying companies—all of whom must cooperate if this new total system of electric on-the-road traffic can be developed successfully. We have already some practical experience, and a lot of U.S. specialists will be able to report about our activities. Some examples are: The first public bus lines in the world for daily use converted from diesel buses to 20 electric buses, and a fleet of nearly 50 battery powered vans which are now under test on the road.

Our work is based on the same findings which are so excellently listed on page 2ff of your report. May I add two additional arguments which finally convinced the German automobile manufacturers, who in the beginning were quite reserved like their colleagues worldwide, to cooperate.

Argument 1.—Petroleum resources are running out and in the future mainly automobiles will be fueled only by secondary energies converted from nuclear energy, coal and water. Such secondary energies can be liquids like methanol, gases like hydrogen, or electricity based on a well-known system for generation and distribution. The production of all secondary energies is impossible without nonnegligible losses.

Electricity will use primary sources with highest efficiency, but undoubtly all three secondary energies will play their part as well in the economy and traffic systems.

Argument 2.—Nearly 75% of the today's petroleum production is used by about 20% of the world's population living in highly industrialized countries.

Underdeveloped countries use only 20%. The western world spends a lot of money to increase its state of development but it will take decades to make the engagement really visible. Just at that time when cheap petroleum runs out, the underdeveloped countries will need it as the basis of relatively simple technologies.

We cannot expect that they start their industrialization and motorisation on such highly sophisticated systems as nuclear energy or hydrogen.

As your honourable President declared during the last World Energy Conference in Detroit the western world is responsible for the future of the underdeveloped countries. We must begin as quickly as possible to use those technologies which conserve petroleum for the future of the underdeveloped nations.

Only electricity has such a high state of art in production, distribution and propulsion equipment that the envisaged development can be done quickly enough.

With your permission, Sir, and based on our experience I would like to make a final remark.

The electric automobile must be considered not only as a vehicle with electric propulsion equipment powered by a relatively heavy battery which is recharged from an electric plug at home.

Indeed it is a complete new system of mobility on the road, mainly characterised by the fact that the load density of an electric distribution grid is by the factor 1000 smaller than the one of the gasoline pump.

Dimensioning of all the components must keep in mind this technical fact, and to ensure that mistakes in this field are avoided it would be useful to foster those R. and D. activities in which all the four elements (automobile, electric motor and control, battery and electricity supply) are represented.

Please excuse, Sir, that a citizen of a foreign country presumed to comment on a bill committed to the parliament of the world's largest nation. I did it feeling the importance of the subject for the future of the whole world.

I am authorized to offer any cooperation of my company GES and their above mentioed cooperating partners.

May I kindly invite you to meet us in Dusselodorf in order to see the first results of our work. Of course I would be also at your disposal, if you wish more information, either by letter or by personal contact in your country.

Hoping that my letter will find your interest I remain, Dear Sir,

Very truly yours,

HANS-GEORG MÜLLER.

Enclosure No. 1
May 30, 1975

Vol. 4 No. 1

FEBRUARY 1975
(Published Quarterly)
$3.00

Electric Vehicle News

The Magazine Committed To Better Transportation

REPORT ON ELECTRIC VEHICLES IN EUROPE
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3rd ANNUAL EV DIRECTORY ISSUE

If It's Battery Powered, You're Talking Our Language

The Electrobus Division of Otis Elevator Company has successfully demonstrated to mass transit authorities across the country that a well designed battery-powered bus can meet their performance requirements.

The Electrobus, a quiet, clean, non-polluting vehicle, was developed from the ground up to be a purebred. It has a low center of gravity, providing excellent ride and handling characteristics without sacrificing load-carrying ability. It is 25 feet long, has a 20-passenger seating capacity and a curb weight of 9,500 pounds.

Its power center consists of a series-wound, 50-hp DC traction motor directly connected to the rear drive wheels, a low-voltage electromechanical controller and, at the heart of the system, a 72-volt Exide lead-acid battery capable of delivering a sustained acceleration of over 1,500 amperes.

Work continues on high-performance electric vehicle batteries at ESB. Talk to us about your needs. Call or write Jim Norberg, Electric Vehicle Department, ESB Incorporated, 5 Penn Center Plaza, Philadelphia, Pa. 19103. (215) 564-4030.

ESB INCORPORATED (ESB)
WORLD LEADER IN PACKAGED POWER

Electric Auto Association

1674 Merrill Drive, #12 San Jose, Ca. 95124

Honorable Congressman

All members of the Electric Auto Association are very much elated about the "Electric Vehicle Development and Demonstration Act of 1975" and pledge a full support for the proposed Bill HR 5470 with hopes of it's early and successful passage by the Congress.

Frankly, it's about time that we undertook a nationwide effort to provide the first step in the eventual electrification of personal transport by adapting the electric auto as the only viable solution in our energy crisis. It is also proper that we should join other nations on this planet in this effort which was started several years ago by England, Japan, Italy and others.

The Bill itself is well put together and it is evident that this was done by individuals well acquainted with this particular field. However, there are some points we wish to make, basically for the sake of conserving expenditures on certain proposals.

On promoting basic research - R & D in this field has been going on for the past 20 years and many millions were wasted in trying to come up with an electric Cadillac instead of an electric Model T Ford. Instead of this wasteful and unnecessary repetition a concise Report on the present State of Art would bring up a good indication where we are and where to start the new program.

At the beginning the Administrator could make use of an Advisory Board composed of sufficient number of individuals, qualified by actual experience in particular specialty , such as electric motors, speed controls, traction batteries etc. Each specialty group should consist of several individuals in order to provide a concesus of decision based on real facts rather than theory.

The development of performance standards and criteria would be helped by inspection and demonstration of more than 50 already available electrics developed by individuals, members of the EAA and other organizations. Such demonstrations could be arranged on a regional basis by special investigating teams collecting the necessary data. This in fact would be a part of the Report on the State of Art.

On studies and research on incentives to promote consumer acceptance of electric autos -- the EAA has been doing this for the past six years by staging Exhibits of the vehicles built by the members in various shopping centers around the SF Bay Area; at least 30 such Exhibits have been made and more are scheduled for this year. The public reaction shows that the elcars, such as they are today, are acceptable by a large segment of the public visiting the Ehibits.

Besides the Ehibits the EAA conducted in 1970 a "Build-your-own Electric" Contest for high school students inthe Bay Area and the winners came up with an electric motorcycle capable of 65 mph top speed and 50 mile range. This type of Contest could be coducted nation-wide for high school and college students. The EAA could provide practical assistance in organizing and conducting such a Contest, which would help to awake the public at large and learn to accept the reality of the coming change.

The EAA is willing to share the experience of its members in designing and building of electric autos, which is represented in seven EAA Chapters in California by more than 250 members and well over 50 electrics built by them since 1967.

Respectfully yours
Walter V. Laski
Walter V. Laski
Founder

ELECTRIC DYNAMICS CORP.
607 North Main Street • Plainwell, Michigan
Phone (616) 685-6828

June 27, 1975

Mr. Mike McCormick, Chairman
Subcommittee on Energy Research, Development,
and Demonstration
1205 Longworth Office Bldg.
Washington D.C. 20515

Dear Sir:

In regards to your letter of June 23, 1975 to Mr. Jim Boylan of Electric Dynamics. I wish to act on his behalf and submit to you our interest and intent on electric vehicles.

We have at this time, two prototype chassis running and are in the final stages of having our mold completed and extracting bodies of fiberglass for the chassis. By the 15th of August we should have two complete units running on the road.

At such time we will have statistics to support our anticipated speed and distance figures. At present with the chassis we are getting approximately forty five miles per hour, with a range of approximately 50 miles. We are confident that after we get the body on the chassis we will increase both the speed and range by benefit of the aerodynamics.

The handling, braking, and riding comfort of the chassis has proven to be of excellent qualities.

We are very much interested in supporting H.R. 5470 and wish to be considered as a participant in researching and developing this program.

Very Truly Yours,

ELECTRIC DYNAMICS CORP.

Jesse W. Penn

Jesse W. Penn
Vice President

JWP/pjh
Enclosures 2

TENTATIVE SPECIFICATIONS FOR THE X2

Wheelbase	78 inches
Tread - front	50 3/4 inches
Tread - rear	53 7/8 inches
Length	144 inches
Width	62 inches
Height	50 inches
Weight	1900 lbs. (approx.)
Horsepower	8
Voltage	72 D.C.
Control	Electronic
Seats	2 Passengers

Tentative Performance

		Range
Top Speed	58-60 MPH	45-50 miles
Cruise Speed	35-40 MPH	50-70 miles
Low Speed	30-35 MPH	70-85 miles

Recharging time	8-10 Hrs.
Battery life	2 years with proper maintenance
Battery pack change time	Approximately 15 minutes.

X2
by
ELECTRIC DYNAMICS

ESB INCORPORATED

SUBSIDIARY OF THE INTERNATIONAL NICKEL COMPANY OF CANADA, LIMITED

CORPORATE HEADQUARTERS
5 PENN CENTER PLAZA, PHILADELPHIA, PENNSYLVANIA 19103

July 2, 1975

STATEMENT OF
ESB INCORPORATED
ON H.R. 5470
TO THE
SUBCOMMITTEE ON ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION
OF THE
COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

JULY 3, 1975

ESB appreciates the opportunity to submit a statement to the Subcommittee on H.R. 5470. We believe the "Electric Vehicle Research, Development, And Demonstration Act of 1975" is a timely piece of creative legislation. We endorse thoroughly the goals of the bill, we support vigorously the provisions of the Act for achieving them; and we sanction strongly, as the primary goal of the Act, the demonstration of the commercial feasibility of electric cars.

ESB Incorporated, formerly The Electric Storage Battery Company, is one of the world's largest manufacturers of storage batteries, with 106 plants in 18 countries. Of these, 51 are in the United States. While ESB is now a wholly-owned subsidiary of The International Nickel Company of Canada, Limited, a Canadian corporation, ESB is registered as a Delaware Corporation and maintains its principal corporate offices in Philadelphia, Pennsylvania.

Historically, ESB has been a major supplier of storage batteries to makers and users of off-the-road electric vehicles such as lift-trucks, mine locomotives, golf carts, and in-plant personnel carriers. In addition, since 1957, our Company has been involved continuously in a variety of projects having as their ultimate objective the creation of an on-the-road electric vehicle market. We believe ESB has earned valid credentials in the field of battery-powered electric vehicles.

From this background, we would like to submit our thoughts on three questions bearing on the intent and implementation of H.R. 5470:

.....Can useful demonstration electric cars be produced with current technology, specifically, with today's lead-acid batteries?

.....Is there lasting value to an EV demonstration program?

.....Will improved electric vehicles result from the activities stimulated by H. R. 5470?

We answer each of these questions affirmatively.

First, the EPA sponsored study "Impact Of The Future Use Of Electric Cars In The Los Angeles Region" was used as an authoritative reference by several witnesses at the June 1975 hearings of the Subcommittee to point out several limitations and shortcomings of lead-acid batteries as an energy source for electric cars. We would like to call attention to the conclusions contained in Volume I of this study, pages 12 through 14.

Conclusion 1 contains this statement: "Electric car range and performance can be adequate for substantial urban use. Even limited-range lead-acid battery cars could replace a million second cars in the Los Angeles area in 1980 (17% of all area cars) with little sacrifice in typical driving patterns."

Conclusion 7, second sentence, reads: "The energy storage capability of even the lead-acid battery is adequate for significant urban use in the Los Angeles region....." This is a flat contradiction to those skeptics who believe today's technology is not adequate for a demonstration program.

ESB's eighteen years of experience with the developers of on-the-road electric vehicles reinforce those conclusions. We believe there is positive evidence, including the experience of present users of electric vehicles, that the energy storage capability of the lead-acid battery is adequate for significant urban use.

Secondly, the value of demonstration programs should not be underestimated. Just as "one picture is worth a thousand words," a demonstration can make people move, whereas continuing talk about the subject to be demonstrated will usually generate only more talk.

Almost all new products have shortcomings. Nothing drives this home faster and provides corrective action more quickly than getting a product into the hands of the customer. American industry believes this and practices the principle involved. In the era since World War II, the use of scientific test-marketing has earned an accepted place as a most useful tool for enlightened corporate management.

It is also common industrial experience that engineers never quite feel their product is "ready" for the market. They invariably want to make "a few more improvements" before releasing it. "Just a few more years of development" is a common plea. However, there comes the time when the product must be taken from the hands of the engineers and left to the final judgements of the marketplace.

Based on our experience with the nascent electric vehicle industry, we are confident that the technology is advanced sufficiently to gain product acceptance in the marketplace. A significant demonstration program will illustrate this acceptance and market potential, and this recognition will result in a steady flow of improvements at an accelerated rate.

Also, ESB is confident that this accelerated activity in the electric vehicle marketplace will stimulate improvements in the lead-acid battery. Our confidence stems from a belief that (1) batteries now being used are "make-do" applications of products designed for other purposes, and (2) the knowledge gained so far will enable the industry to move quickly in the right directions for a series of incremental battery improvements that will add up to better vehicle performance.

Our advocacy of the present day lead-acid battery does not imply that we are blind to the possibility of improved technology. In our opinion, the true electric vehicle battery has not yet been designed. But, there exists a reservoir of knowledge about battery constructions for other purposes that seemingly could be pulled together to produce a more satisfactory product. As the Los Angeles EPA "Impact Study" points out, "Long life and low initial cost are thus vital objectives for better research." The industry knows how to make "long life" batteries. We also know how to make "low initial cost" batteries. With adequate incentive in terms of a stable and growing market, we are confident we can find ways and means of approaching the goal of doing both at the same time.

Finally, we believe that the combination of activities contained in H.R. 5470 -- demonstration, development, and research -- will result in improved electric vehicles for both the short and long terms.

In addition to the judgement of the marketplace during the demonstration phase, the acceleration of product improvements and the growing perception of a stable market will encourage not only the efforts of the vehicle and component makers now in the business, but also will encourage others to enter the field with their own ideas and plans. The beneficial action of competition will ensure near term improvements.

With respect to the long term, H.R. 5470 envisions a broad analysis of all factors affecting the feasibility of the extensive use of electric vehicles. This will result not only in focusing attention on the desired institutional environment, but also will encourage the optimum wedding of improved technologies that will result from the demonstration program. In light of the critical need to realize maximum energy efficiency in the nation's transportation system, we believe these are desirable and essential steps that must be taken. The proposed Electric Vehicle Research, Development And Demonstration Act Of 1975 combines the proper role of the public and private sectors in this effort, and we support its enactment.

FREDERICK J. PORT
President

COMMENTS FOR THE HEARING RECORD ON H.R. 5470

Submitted by

G. Rogers Porter
of
ELECTRIC VEHICLE NEWS

Westport, Conn. 06880

Thank you for the opportunity to enter comments into the hearing record on H.R. 5470.

By way of identification, I am President of Porter Corporation, owner and publisher of Electric Vehicle News and also serve as the Publisher and General Manager for the magazine. The magazine has been published quarterly since February 1972. The purpose of the publication is to foster orderly growth and development of the electric vehicle industry. The magazine strives to achieve its goals by publishing news garnered from worldwide sources of events and developments related to electric vehicles. The magazine is generally considered a news and promotional medium more than a publication devoted to in-depth technology reports. The magazine has subscribers in approximately forty countries, altho it is printed only in English. The circulation averages approximately 20,000 copies of each issue. It is the only international magazine of its kind, devoted exclusively to the field of electric vehicles.

Thus, knowing the interests and concerns of Electric Vehicle News, it is obvious that my support of H.R. 5470 is substantial, indeed. Since my work involves continuous study of efforts and attitudes of all segments making up the whole of this industry I will presume to consider myself as being objective in an analysis of the industry -- except for a dogged belief that electric vehicles must be and will be developed to the point where they become a major factor in the over-all transportation scheme.

Since H.R. 5470 deals with on-the-road electric vehicles, I will ask that my comments be considered as related basically to this category. However, as a passing observation, we have witnessed strong growth in the use of electric vehicles in off-the-road uses. The refinements in such vehicles may suggest that on-the-road EVs also can be expected to be improved and serve more needs once proper support is given to their development and introduction in sufficient numbers to "prime the market" to levels at which the free enterprise forces may operate successfully.

Being international in editorial scope Electric Vehicle News has observed certain worldwide circumstances which I believe are worth mentioning. It has become quite obvious in the EV field (~~as in certain other fields)~~ that the United States, at this time, does not have any significant technological advantages in the development of battery-powered on-the-road vehicles. In fact, Japan may be slightly more advanced than the USA -- adding promptly, however, that the advancements in Japan are more related to refinements of presently known technology than to any new technical know-how which the USA does not possess. In the August 1974 issue of Electric Vehicle News we carried an article prepared by Mr. Gordon W. Johns, of the Dana Corporation. Mr. Johns was a member of a group, sponsored by Electric Vehicle News, which had toured and inspected electric vehicle facilities in Japan in April 1974. Mr. Johns reported specific data on Japan's on-the-road EVs at that time. The performance figures were impressive, indeed. But Mr. Johns concluded his article by writing:

> "In summary, we would like to say that we feel the Japanese are no further ahead of the U.S. in technical progress. We do feel they are far ahead of us with actual plans to put hardware in production. They are not going to wait for the final battery, but will begin with the lead-acid and improve upon it as time passes".

We are often reminded that England has more on-the-road electric vehicles in service now than the rest of the world combined. That is an interesting fact --- but somewhat unrelated to the spirit of what we hope to achieve with aid of legislation such as H.R. 5470. We must remember that our goal is improve the EV -- not to be content with the reliable plodding cumbersome vehicle of the Victorian era or the 1920's. This is an image that should be erased from our minds -- and, in my opinion, is being erased now. More modern vehicles will do the job faster. Would you be satisfied with the Chevrolet Baby Grand (circa. 1920s) yourself? But, according to our information, the English are concerned that their EV industry is not striding ahead -- despite their current in-use EV population. As a conjecture, the English could take steps soon to capitalize on their EV "history" --- even to the point of utilizing the government's position now in conventional auto production.

In France, in 1973, Electricite de France had a few Renault conversions on hand. The one I tested was a viable automobile, indeed. But, at that time, Renault (state-owned) was not willing to supply Electricite de France (state-owned) with any substantial number of conversions. As I understood the reasoning, Renault had a strong market for products of a very sophisticated product systems and did not want to get that production capability "out of tempo" for relatively few cars of battery-power design. But times have changed --- and Renault is even selling frames and chassis to an American EV producer now. It is reasonable to expect that the big three Es -- economics, energy and ecology -- will bring even more pronounced changes in France as well as in other areas. In fact, one very interesting EV has long been in service in Paris. It's the battery-driven garbage truck -- with battery-driven garbage compactor. It certainly improves the "sound track" at 6 A.M. when city folk are struggling for those last few moments of peaceful slumber.

Germany continues with very determined efforts in electric vehicle development. Notable progress has been made in buses -- even the comparatively large buses. Seven battery-powered buses were put into service this year in one West German city. Other cities have had test programs in progress for several years -- with much success, so I understand. In addition Volkswagen has been testing a battery-powered van which is reported to be ready now for mass production. It seems the overseas automotive interests are concerned with actually developing and marketing EVS -- not merely with R&D that gives a "put-down" to EVs.

Italy has a limited EV activity. Australia and South Africa have shown evidences of serious EV efforts. Information comes to us -- rather infrequently, however -- of USSR commitments to battery-powered vehicles. Some declared interests possibly may lag as competition heightens in the field. But, in my opinion, it is not safe to assume that any aggressive society will not pursue EV technology with continuing determination. Certainly, the EV market has not been "cornered" by any country or any company at this time. But we have been experiencing a strong attempt just recently in the field of the electric golf car. With subsidies, a Polish golf car has moved into this country and caused heavy market losses for U.S. manufacturers. But this instance is an under-pricing situation rather than a matter of vehicle performance advantages.

While we are acutely aware of our problems in U.S. cities, it may be difficult to realize that most cities outside our boundaries have problems far more serious than ours. Throughout Europe a number of cities have flatly banned ICEs (internal combustion engines) in thickly-populated heavy-travel areas. In Italy, exhaust chemicals from cars have been blamed for actually eroding statuary and ancient buildings. For some years Tokyo has been cited as the horrible example of all smog-laden communities.

But these problems continue to be compounded. For instance, petrol in England is now near the $1.50 U.S. gallon level; in Rome, it's going at the equivalent of $2.00 per gallon. As you know, some countries found it necessary to impose driving bans that were more far-reaching than many USA citizens can envision.

My intent, however, is not to be an alarmist. My purpose is to remind us that the need for battery-powered on-the-road vehicles appears to be considerably greater in other areas of the world than in this cpuntry. It logically follows, in my mind, that (1) we can expect increasingly intensive efforts in EV development from these areas and (2) we ourselves are under-estimating the needs of other countries and, also, our own needs. We have waited too long now for a strong introduction of EVs onto the U.S. transportation scene -- and the longer we delay strong positive action the more dire the results to be faced in a future that's all too near.

Currently our USA auto manufacturers are under pressures to build smaller cars that use less gasoline. Let's remember that the non-USA auto manufacturers have had similar pressures for many years -- even before the radical increases in crude oil cost. It would appear that in Europe, for instance, the economy has never been able to tolerate automobiles so expensive to own and operate as the commonplace USA cars to which we have become accustomned. But the American consumer has "had it", so to speak -- and will no longer be victimized by the juggernauts that guzzle gasoline and demand outrageous sums when too-frequent service is required. It's the American economy, too, that also can no longer tolerate the burden thrust upon it by an industry which appears unwilling to be satisfied with a fair and rational proportion of the income of this nation's citizens. We cannot deprive ourselves of individual mobility. We cannot bankrupt ourselves. We have the streets and highways which represent investment of billions of dollars. You might say we have an existing system that almost works -- but surely needs change. We have seen our USA auto industry resist change in past years -- and such resistance is a luxury we cannot permit again. A system that almost works is not enough!

During the past few years we've heard all kinds of comments on why the EV could never be a viable on-the-road vehicle. Not a suitable battery. Not enough range. Low speed. And numbers of other negative comments. But times have changed. Yesterday's non-believers are taking a second look -- and seem to be liking what they see. But the most desperate defenders of ICEs now appear to be mustering a new thought --- that being that we shouldn't bring electric vehicles into the scene because of economic damage that would be inflicted on the automobile industry -- an industry upon which so many of our people depend for a livelihood. It seems to be a last-ditch stand against EVs -- and the most irrational of all the attacks ever mustered against EVS. The fallacies of such thinking are too obvious -- and too numerous -- to point out in detail at this time. But this is not a situation for competition anyhow -- ICEs against EVs. It's a situation in which a need must be met for the common good of society as a whole. We have needs -- dire needs -- that only can be met at this stage of our technical know-how by battery-powered on-the-road vehicles.

Perhaps I should emphasize, however, that as an industry observer and participant I have absolutely no desire to take any blind "pot shots" at the automotive industry as it exists in this country today. If other critics wish to do so -- thatsis their concern. My interest is simply to get electric vehicles in use, performing the limited services which they can provide best. I do not see any indications that any American automotive manufacturer, with the exception of American Motors Corporation, through a subsidiary, has any intention of fostering development and growth of EVs. I hope I am wrong -- and I may be. After all, the so-called Detroit interests have a pretty good track record for keeping many new ideas under wraps until carefully-planned marketing strategies and production schedules can be arranged to their own satisfaction. But no matter what Detroit's reasoning may be, we can't wait on EV development. We need it now. Then possibly the big automotive manufacturers can give the final big boost to the EV industry once better EV acceptance is gained and the Detroit know-how in mass production, distribution and service is needed to truly stabilize the EV industry. Such capabilities, I feel, will be warmly welcomed by many -- especially consumers, who urgently need a low-priced reliable personal vehicle that conforms to demands of economy, energy and ecology.

Almost immediately after information on H.R. 5470 became generally known in the EV industry, we at Electric Vehicle News began getting many questions about the bill -- along with many comments from those who had studied the bill carefully. The most common doubt expressed by industry members might be summarized as: "But it'll be the big guys who want the kill the EV who will get all the money". From my listening post, this appears as a very real fear in the minds of many dedicated and talented people. Realistically, I personally take a modified position on this matter. In effect, I believe that individuals who have exhibited ability in EV development and production should be involved in a program such as proposed by H,R. 5470 -- no matter what size company they work for. But are these judgments left too much in the hands of an administrative team? Are there additional safeguards that can prevent vast sums getting into hands of companies or individuals who are not qualified or, worse yet, who would actually retard progress in EV development and growth? Would it be feasible to establish bench marks to determine performance against contracts issued, so that waste and bad performance could be held to a minimum? I would assume similar questions must arise every time our Government embarks on any major developmental program. Nonetheless, such questions are real and valid. Can the bill be strengthened in this area?

The administration of H.R. 5470, in fact, appears as tho it would be a most difficult task, indeed. Many judgments must be made -- many based on very limited facts. As I envision the program there might be a need for skilled crews giving almost constant surveillance to many projects simultaneously. Yet we would not want to deprive industry of skilled people needed for actual project performance. Nor would we want an over-load of administrative people. But there will be management problems inherent to any operation of this magnitude. We might suggest that deep consideration be given to any anticipated errors or omissions in administration of the bill. In the parlance of football -- the plays are good, the signals are called, but have we any assurance we have the right players in the game?

It is my opinion that H.R. 5470, as written and with sound administration, can provide the industry with necessary aid for building EVs into a meaningful position in the total transportation needs of our society. The on-the-road electric vehicle is much more than a mere commercial venture -- it is a very human, very individual need -- let's hope it will be so regarded and nurtured. Our citizens take pride in fights against social ills -- against polio, cancer, and so on. While great American industries have given us many products for the healthier and happier life, we won't continue having the better life unless we recognize that change is needed. And now is the time when change is not only needed but necessary. Yes -- Electric Vehicle News favors strongly the basic mandate as described in H.R. 5470.

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FACTS

about

ELECTRIC VEHICLE NEWS

History: Details for producing the first USA-published magazine for the electric vehicle industry were worked out during 1971 between the Electric Vehicle Council and G. Rogers Porter (now Porter Corporation). Electric Vehicle News (EVN) was to be fundamentally a news magazine for all electric/battery driven vehicles of all types -- worldwide. EVN, published quarterly, remains the only USA-based publication for this field. The first issue appeared in February 1972 -- Vol. 1, No. 1 -- with a guaranteed circulation of only 10,000 copies per issue.

Editorial policy has consistently followed the pattern which was initially established. EVN is edited to the interests of EV users and potential users, of manufacturers of EVs and EV components, of others who are concerned with EV growth; also to the interests of electric power companies, governments and transit authorities, of EV hobbyists, R&D centers, universities and other individuals concerned with EV developments; and of conservationists and environmentalists.

News stories in EVN deal with EV developments, case histories, new products, events of significance, special articles. The standard EVN 4-color cover, showing various EVs in panel display, has become a strong identification for the magazine. Photographs are used liberally. A special section, TidBits, gives tersely-worded information on many EV-related subjects in "newsletter" style. Editorially, the span is truly international -- as the publisher views this new industry as being of concern to all developed nations and most of the emerging ones. Also, most major nations having sound technical skills are making rapid strides in EV research, engineering and even production.

Most issues to date have reflected editorial/advertising balance that is approximately 70% editorial and 30% advertising.

A "Directory" for the total EV industry had never been produced until EVN published it in the February 1973 issue -- "EVN's 1973 International Directory of the Electric Vehicle Industry". The Directory was incorporated in the February issue as a sixteen-page section. The Directory is an annual feature -- each February.

Circulation balance could not be accurately measured during the early issues due to extremely rapid growth. Those who aided materially in circulation growth were electric utilities, various associations around the world, the manufacturers themselves and, of course, the Electric Vehicle Council. However, business interests of readers have since been fairly well identified -- as given in following data.

Circulation grew from 10,000 to approximately 20,000 during EVN's first year -- and, at this time, it appears that a 30,000 print order will be needed for the start of EVN's third year -- February 1974. Initially, group subscriptions placed by electric utilities gave EVN a circulation base. There are 48 such utility subscribers now -- they provide hand-picked EV users, prospects and others which we add directly to the EVN subscriber list and they are paid circulation. But individual subscribers now out-pace the groups in the growth pattern -- and at fully paid rates of $8.00 per year for USA and $10.00 per year outside USA.

Concisely -- it appears that those persons who genuinely are involved in EVs have learned about EVN and are subscribing. The meaningful EV-ers have found EVN and read it with expressed enthusiasm.

Today: Editorially, the policy remains the same -- EVN is edited for firms and individuals concerned with engineering, research, design, manufacturing, marketing and actual use applications of all types of electric vehicles. (Re-read the previous page for more detailed description.)

EVN is published quarterly by Porter Corporation, issue datelines being February, May, August and November.

Currently, advertising rates are based on a 15,000 circulation -- as circulation auditing has been unable to keep abreast of EVN growth. Identifiable circulation, for the first 6 months of 1973, breaks down as follows:

USA	---	14,976
Canada	---	295
Int'n'l	---	1,336

Occupational Interests:

Industrial; local fleet operators; in-plant fleet owners; resort/recreational mgmt.; real estate mgmt.	8,960
Gen'l. Mgmt; electric utilities; affiliated energy interests	2,872
Nat'l., state and local gov't. officials; transit mgm't; environmental authorities; R&D groups; transportation	2,370
Mfrs. of EVs and EV components; EV dealers and distribs.	825

Libraries, universities, EV hobbyists; others	1,580
Un-paid (promotional)	676
	16,607
Bulk distributed by mfrs., utilities, others (average)	4,100

Circulation growth has been substantial since the first six months of 1973 -- and, as mentioned before, the publisher visualizes a circulation base possibly as high as 30,000 beginning 1974. Efforts to build circulation have been minimal -- thus, in the publisher's estimation, EVN enjoys coverage basically of the truly "hard core" of those determined to promote EV growth -- in other words, an "elite" of the EV interests worldwide.

It's good business to develop a developing market -- and the EV market is developing. Some well-wishers of EVN contend that this publication has been the single means of bringing the EV industry into focus and has done more to advance its growth than any other supporting action during the short existence of the magazine. Whether or not this is an accurate evaluation -- EVN will still strive for the sound, rapid and profitable growth of this business. The world needs transportation of the sort which only EVs can provide -- thus EVs are sure to get where they belong!

Position yourself NOW -- let your advertising give you identity NOW with the EV industry.

AMERICAN PUBLIC POWER ASSOCIATION

2600 VIRGINIA AVENUE NW WASHINGTON DC 20037 • 202/333-9200

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Jacksonville, Florida

WALTER R WOIROL
PUD #1 of Chelan County
Wenatchee, Washington

July 3, 1975

The Honorable Mike McCormack
Chairman
Subcommittee on Energy Research,
Development & Demonstration
B 374 Rayburn House Office Building
Washington, D.C. 20515

Dear Chairman McCormack:

Enclosed are six copies of a statement by the American Public Power Association in support of H.R. 5470, the Electric Vehicle Research, Development, and Demonstration Act of 1975. I would appreciate it if the text of the APPA statement could be inserted in the hearing record on H.R. 5470.

Sincerely,

Alex Radin
General Manager

AR/dt
Encl.

Statement on H.R. 5470
Submitted by American Public Power Association
To House Subcommittee on Energy Research, Development, and Demonstration
July 2, 1975

The American Public Power Association, representing more than 1,400 local, publicly-owned electric utilities across the country, strongly supports H.R. 5470, the Electric Vehicle Research, Development, and Demonstration Act of 1975.

Awareness of the advantages of electric vehicles is growing as the need for energy conservation becomes more apparent. For example, the House of Representatives, on June 13 agreed to an amendment to the energy tax bill, H.R. 6860, the Energy Conservation and Conversion Act, allowing a tax credit of 25% or up to $750 of the amount paid for an electric vehicle. In addition, a bipartisan group of 66 Members of the House have indicated their support of electric vehicles by sponsoring H.R. 5470 or similar legislation.

APPA supports H.R. 5470 because it believes enactment of the bill will help demonstrate the benefits of electric vehicles, including efficient use of electrical generating plants, conservation of petroleum, and reduction in air and noise pollution.

Electric vehicles would permit more efficient use of electric plant capacity since their batteries would usually be recharged at night during electric generating off-peak hours.

About one-fourth of the total energy in the United States is guzzled annually by our transportation systems; about one-eighth of the total U.S. energy is consumed by automobiles according to the Energy Research and Development Administration (ERDA). There are approximately 100 million vehicles powered by petroleum in the country. Currently, the U.S. cannot fulfill 35% of its oil needs from domestic sources and must import about 6 million barrels a day of foreign oil. Gas prices at the pumps are anticipated to rise to 70¢ in September. It is apparent that an alternative to petroleum to power vehicles would cut some of the country's dependence on foreign oil.

The electric car is noiseless and does not pollute the environment. About one-half of the total automobile miles driven today consists of trips of 5 miles or less. Envisioned as a second car, the electric vehicle is to be used around town for these short trips and errands. Approximately 80% of urban traffic is stop and go, and this is when conventional internal combustion engines release the most harmful gas fumes. The electric vehicle has no pollutants to release and does not use energy when it is standing still.

It is true that pollutants will be released from the electric generating plant if coal or oil is used as a fuel, but these emissions from a stationary facility are easier to control than those from moving vehicles. Moreover, most generating plants are not in the heart of an urban area. There of course will be no air pollution if hydro or nuclear power are used to generate electricity for the cars.

APPA supports the basic aim of H.R. 5470, which is to develop a vehicle that is commercially feasible to meet the transportation needs of the country and that will not depend on petroleum for power. The bill calls for a three-year research, development, and demonstration program costing $40 million annually. ERDA would contract with private industry to produce and develop within one year 5,000 electric vehicles using conventional automobile chassis. ERDA would contract for another 5,000 vehicles to be leased throughout the country within three years as part of the research information gathering and demonstration project. Leasing to the public would provide valuable information on the operation of the car, and the reaction of consumers. These vehicles in the second phase would use frames especially designed to maximize electric power. Production of up to 10,000 vehicles is expected to stimulate the industry and promote competitive development.

APPA is especially pleased with the section of the bill that provides for research and development of batteries for electric vehicles. Nine years ago, APPA presented testimony before a Senate Subcommittee on Air and Water Pollution, urging the development of a lighter, longer-lasting, and less expensive battery for electric vehicles than was then in existence. Since those years, battery development has progressed so that an average range of an electric vehicle is 60 miles with a speed up to 50 miles an hour.

However, according to ERDA testimony before this subcommittee on June 3, lack of sufficient progress in improvement of the lead-acid battery is the one obstacle to complying with the bill's goal of producing up to 10,000 electric vehicles in three years. Dr. James S. Kane, Deputy Assistant Administrator for Conservation of ERDA said, "The single most important drawback of the only currently available battery (the lead-acid battery) is its high life-cycle costs due to its relatively short life. This cost factor is the main deterrent to widespread use of electric vehicles today."

APPA suggests that in carrying out the section of the bill calling for testing and evaluation of available batteries, ERDA include batteries from other countries. For example, Toyota of Japan has recently announced its development of a five-passenger electric car prototype that has a 125 mile range at a speed of 58 miles an hour. There are about a million electric vehicles in use throughout the world. Although 90% of these are off-road vehicles, there would certainly be merit in examining their components.

Continuing its interest and involvement in the development of electric vehicles, APPA has participated with a group of electric utilities in the purchase of over 100 Battronic trucks to be used for light general utility delivery. In addition, the Electric Vehicle Committee of APPA has an on-going study of electric vehicles and will meet in September to review developments.

In conclusion, APPA supports H.R. 5470 as a means to actualize the country's technological potential to develop a fuel conservative, cost effective, and ecologically sound electric vehicle.

C&D BATTERIES DIVISION
Industrial Batteries and Chargers
3043 WALTON ROAD, PLYMOUTH MEETING, PENNSYLVANIA 19462
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NEMA
MEMBER

July 21, 1975

The Honorable M. McCormack
House of Representatives
1503 Longworth Building
Washington, DC 20515

Subject: House Bill H. R. 5470

Dear Mr. McCormack:

Recently we obtained a copy of your joint-sponsored bill, H. R. 5470: "Electric Vehicle Research Development, and Demonstration Act of 1975." You have obviously accomplished a thorough examination and summary of the needs that must be met if the worthwhile goals of: promoting electric vehicle technologies and demonstrating the commercial feasibility of electric vehicles, are to be achieved in the near future.

We wholeheartedly endorse your efforts and support the enactment of this bill, believing that its passage will provide a new catalyst for further development and promotion of electric road vehicle usage in the United States. Already, there are signs that off-shore electric vehicle technology is moving forward at a rapid pace, and may be imported to fill a domestic void.

C & D Batteries Division has a full, continuing interest in developing and applying improved battery energy storage systems; we have internal as well as joint research projects currently underway to this end. We do conclude as one result, that the lead acid battery is the only electric vehicle on-board energy source that can be counted on for at least the next three to five years. I am enclosing a copy of an article I wrote on electric road vehicle fuel systems which elaborates this point. Shown on page four, the availability dates projected in 1974 for those battery systems under development seem now to have moved out at least another year. As a further illustration of the elusiveness of the more exotic battery systems under investigation, Ford Motor Company was reported in 1967 to be aiming at producing a full-scale sodium-sulfur battery by the early 1970's ("U. S. News and World Report" March 20, 1967, page 74). Now, 1985 appears to be the earliest projected date (also see "Industrial Research," June, 1975, page 59).

However, we estimate that accomplishing the research and development specified in section six of your bill can increase the performance of electric road vehicles powered by lead acid batteries at least 30 to 50 percent over present speed and range capabilities. This can stimulate the user acceptance needed to put "significant numbers" of electric road vehicles into practical use within a short time - a domestic electric road vehicle population of 100, 000 by 1980 is a very realistic goal.!

We will be pleased to provide further information that you and your co-sponsors and colleagues may feel useful to have from us. Thank you for your attention.

Cordially,

Edwin C. Read

Edwin C. Read
Manager - Marketing Research

cc: The Honorable Richard S. Schweiker
The Honorable Hugh Scott
The Honorable R. Lawrence Coughlin

PLANNING AND UTILIZING CURRENTLY AVAILABLE FUEL SYSTEMS FOR ELECTRIC ROAD VEHICLES

BY

EDWIN C. READ
C & D BATTERIES DIVISION
ELTRA CORPORATION

3043 Walton Road
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SUMMARY

Electric powered road vehicles are being marketed today which can directly replace internal combustion engine vehicles for many practical applications. The speed and range performance of these electric vehicles is not on a par with their I. C. engine vehicle counterparts, due largely to the lower energy delivery capability of "electric fuel" compared to petroleum based fuel. However, if certain design, application and usage parameters are optimized by the electric fuel supplier as well as the electric road vehicle manufacturer, the electric vehicle user will experience no performance shortcomings and enjoy many service benefits.

INTRODUCTION

Today's users of on-the-road vehicles are conditioned to:

--Expect virtually unlimited operating range, with speed and other performance characteristics limited mainly by laws and regulations.

--Be interested in but not basically concerned about efficiency and economy of operation.

--Accept a relatively high vehicle maintenance frequency and cost as part of the price for high performance.

In contrast, because of restrictions placed on the electric vehicle manufacturer by the capacity and delivery limitations of the electric fuel tank, electric road vehicle users will have to become accustomed to:

--Taking up to eight hours and even longer to refuel their vehicles instead of only a few minutes.

--Driving a vehicle with a limited operating range as well as limited speed and other performance characteristics.

--Taking advantage of other operating benefits such as economy of operation and reduced vehicle maintenance.

In contrast to the I. C. engine vehicle, the electric road vehicle, in order to accommodate the present limitations of its on-board fuel supply, will be best utilized under urban and suburban driving conditions where design emphasis can be placed on peak efficient performance up to a practical limit.

Bearing in mind the above design and application limitations, and recognizing the need to assist the user in planning for optimum vehicle usage, a number of electric vehicle manufacturers and electric fuel system suppliers are currently engaged in developing and serving a substantial market for electric road vehicles. The purpose of this article is to briefly present the current state of development of electric fuel systems, and to qualitatively review some design, application and usage considerations that will influence the acceptance of electric road vehicles by industrial and commercial as well as private users.

THE ELECTRIC FUEL SYSTEM

The fuel system for electric vehicles consists of the on-board battery (fuel tank) which stores the electrical energy through chemical conversion; the on-board or off-board battery charger (fuel station pump) which converts the Electric Utility energy to direct current energy and automatically fills the electric fuel tank; and the Electric Utility distribution network (fuel refiner).

The following table summarizes the state-of-the-art of some on-board battery systems presently being used or proposed for electric road vehicles:

SOME ELECTRIC ROAD VEHICLE BATTERY SYSTEMS UNDER CONSIDERATION (1)

System	Projected Maximum Performance		Dollars Per KWH	Cycle Life	Problem Areas	Projected Availability
	Watt Hrs. /Lb.	Watts Per Lb.				
Conventional Batteries						
Lead Acid	15-25	20-30	20-50	300-2000	Low Energy Density	NOW
Nickel-Iron	20-30	60	20-30	300- 400	Gassing, Maintenance	1976
Nickel-Zinc	30-40	75-100+	20-25	250- 350	Cost, Life, Dendrities	1977
Alkali-Metal-High Temp.						
Sodium-Sulphur (Beta Alumina)	80-100	80-100	20-40	2000	Construction Electrolite Life	1980-85
Sodium-Sulphur (Glass)	80-150	80-400		2000	Life, Glass Stability	?
Lithium-Sulphur	100	100+	20-40	—	Corrosion, Cost, Mat'l.s	1980-85
Other Systems						
Zinc-Chlorine	60-75	50-60	10-20	500-2000	Complexity, Hazards	1978-79

(1) DATA SOURCE:
Automotive Industries, April 15, 1974 Page 31

As seen in the table, the lead-acid storage battery is probably the only electric vehicle on-board fuel tank in practical use, among those systems proposed or under development. Also, it is suggested that availability of basic raw materials and/or the need to fully prove out the reliability and serviceability of the proposed systems may delay their projected availability beyond the dates shown. For the purpose of this discussion only the lead-acid secondary storage battery system will be further considered.

Lead-acid batteries for motive power use, such as on electric vehicles, are designed especially to be deep-discharged and then fully recharged over a period of time known as a cycle. The batteries are usually rated by the amount of ampere-hours (or kilowatt-hours) they deliver when discharged at a constant rate over a fixed period of time, down to a specified final voltage. For example, a battery in good condition, rated 300 ampere-hours at the 3 hour rate should be able to deliver 100 amperes continuously for at least three hours before a final voltage of 1.70 volts per cell is reached.

In general, two types of lead-acid storage batteries are commonly used as electric vehicle storage tanks:

--Automotive or golf cart types -- conventionally available in low height, six volt modules; ratings seldom exceed 250 ampere-hours.

--High Energy Industrial Types -- The two-volt cell modules are furnished completely assembled in a self-contained tray with intercell and external connectors for the vehicle voltage specified. Battery height is usually several inches above that of automotive types; capacities range to 900 ampere-hours and beyond. Most manufacturers of each type of battery have full electric vehicle application data available on request.

DESIGN AND APPLICATION CONSIDERATIONS

Capacity

The overall performance designed into the electric road vehicle is governed mostly by the capacity of the on-board fuel tank--measured in terms of how much total energy it can deliver over a given period of time (KWH/lb), as well as the peak rate at which it can deliver power to the vehicle motor (KW/lb). The vehicle range and payload are dependent primarily on the KWH/lb available, while acceleration and top speed are governed mainly by KW/lb. The vehicle manufacturer does have some flexibility in trading off range and payload for increased acceleration and speed, or vice versa: battery design characteristics can be modified to suit, within limits; adjustable current-limit may be furnished on the vehicle (static) controller, lowered to conserve battery output for longer range or raised to increase battery output for better acceleration.

The electric vehicle manufacturer should also review closely with the fuel tank supplier the expected ambient temperature range of vehicle operation, as battery discharge and recharge capacity are both affected by lower than normal ambient temperature. Various means to improve vehicle performance at low temperatures can be employed, such as recharging in heated areas and utilizing heaters in the battery tray.

Capacity and service life testing standards, e.g. NEMA Standard IB-2-1974, and Federal Specification WB00133B, provide a means for electric vehicle manufacturers and users to determine the expected performance of various lead-acid electric vehicle batteries currently available.

Efficiency

Overall electric vehicle operating efficiency will be the combined efficiencies of the various operating components and subsystems. Since vehicle operating component efficiencies can be affected by the design characteristics of the electric fuel system and the reverse is also true, it is wise for the vehicle manufacturer and the fuel system supplier to coordinate closely to achieve best overall performance efficiency. In this area, the decision of lower first cost versus lower operating cost can be significant.

Some efficiency considerations for the vehicle are:

--Controls -- stepless (static) or step (contactor) type; does the control scheme provide a means for decelerating the vehicle separate from braking (regeneration), and recharge the on-board batteries as well?

--Motor -- does vehicle normal operating speed closely match motor optimum RPM; is motor on-load voltage suited to maintain adequate vehicle performance throughout the duty cycle?

--Drive Train -- are vehicle performance and efficiency improved with or without a transmission?

--Body Design -- are aerodynamic drag and tire-to-road friction minimized?

Some efficiency considerations for the electric fuel system are:

--Battery -- does the design provide low internal resistance consistent with proper discharge characteristics and good service life?

--External Connections -- are all conductors and connectors large enough to take care of maximum current requirements without excessive voltage drop and overheating; are all joints and connections made for lowest possible resistance and minimum maintenance; are cable runs as short as possible to minimize voltage drop?

--On-Board or Off-Board Charger -- what is the overall efficiency over the recharge cycle (KWH out/KWH in); is the charger of sufficient size and proper operating characteristic to fully recharge during the allotted time, with minimum gassing of the battery; is efficiency sacrificed by restricting charger input voltage and/or current to something less than optimum?

Reliability

It is generally concluded that electric vehicles will perform more reliably than their I. C. engine vehicle counterparts, because they have fewer wearing parts and operating stresses are not as severe. However, the electric vehicle will perform only as dependably as its least reliable component will allow. Here again, the lowest first cost will not necessarily afford the lowest operating cost or best user satisfaction.

Some reliability considerations for the electric fuel system are:

--_Duty Cycle_ -- are there adequate safeguards to prevent repeated over-discharge of the battery during regular use?

--_Service Life or Cycle Life_ -- is this deliberately sacrificed by the battery designer or by the fuel system specifier in order to gain increased vehicle performance or lower initial cost?

--_Premature Failure_ -- is there adequate assurance by battery design and standard of manufacture that the electric fuel system components will not experience random premature failures before the end of the expected cycle life?

USAGE CONSIDERATIONS

Operation

Users of I. C. engine vehicles are not conditioned to having operational restrictions placed on them. In the two-car family, the automobiles may differ in size and capacity but, properly maintained, either vehicle can be driven cross-country. The intracity commercial road vehicle differs in design from the interstate vehicle mainly in payload capacity, not in operating range. In short, we are used to driving wherever we want to whenever we want to, with only brief stops along the way for refueling.

As already mentioned, electric road vehicles are not presently so accommodating; but they can serve many transportation needs equally well if their usage is reasonably pre-planned. An excellent example of this is the widespread commercial use in England of electric trucks on preset route pick up and delivery operations. There, considerable operational savings are realized (due in part to extremely high I. C. engine fuel costs), and electric vehicle useful life consistently exceeds ten years.

Maintenance

Currently available I. C. engine passenger and light commercial vehicles have a useful life of about 100,000 miles, with considerable routine maintenance required for the propulsion system but little maintenance needed for the fuel system. In contrast, some manufacturers of electric road vehicles are designing for a useful life of at least 300,000 miles with little maintenance needed for the propulsion system, but with frequent routine maintenance required for the electric fuel system. An electric vehicle operating with a range of 30-50 miles per charge might require battery maintenance every 500 miles as follows:

--Clean and neutralize top of battery with water and baking soda

--Check all mechanical connections.

--Add water to all cells as necessary.

--Check cell specific gravity and voltage readings for proper balance.

Overall electric vehicle maintenance requirements are well suited to the centralized electric fuel service station concept. In fact, many electric vehicle manufacturers feature a quick-change battery design. With this feature, batteries can be exchanged at a central location in about the same time as it takes to refuel an I. C. engine vehicle.

Utilizing the quick-change approach, complete electric fuel system maintenance, including recharging, could be handled at the centrally located electric fuel service station, with vehicle range and the usefulness appreciably increased.

It seems clear then that a user change to electric road vehicles can mean only a routine change in the means of obtaining road vehicle fuel, and user acceptance of electric road vehicles will not be negatively affected by their different fuel requirements.

CONCLUSIONS

These considerations point to the need for joint planning between electric vehicle manufacturers and electric fuel suppliers for the use of presently available electric fuel, if electric road vehicles are to receive widespread user acceptance in the immediate future. It is suggested that airing the problems will stimulate further interest in arriving at the best solutions for increased user satisfaction with electric road vehicles.

1 KG = 2.205 LB.

indicates that the accumulation of Mn_3O_4, and the formation of ZnO-Mn_2O_3, both formed during the discharge process, are significant contributors to the problem.

Other ambient-temperature cells under development include the iron/nickel oxide cell which has a long cycle life, and a specific energy between that of the Pb/PbO_2 cell and the Zn/NiOOH cell. It may prove attractive for industrial electric vehicles. The zinc/chlorine cell is in early development stages. Only short cycle lives have been reported, but it is expected that specific energies near 100 W-h/kg may be realized. This system involves pumps, heat exchangers, and a refrigerator, probably placing it at a disadvantage for use in private automobiles.

In the area of cells with metal negative electrodes and positive electrodes which operate on air (such as Zn/air and Fe/air), the common problem is that of low specific power (generally less than 50 W/kg). This situation is attributable to the fact that air electrodes are not capable of operating at high enough current densities for long periods of time. In addition, batteries with air electrodes which might be used for vehicle propulsion are generally too complex and bulky for automobile propulsion.

And farther into the future

Looking farther into the future, we see the possibility of the use of some systems such as sodium/sulfur and lithium/iron sulfide, which operate at 300 to 500 C. These systems show promise of specific energies near 200 W-h/kg and specific powers well in excess of 150 W/kg. These types of cells are still in the relatively early development stages, but the results have been very encouraging.

The sodium/sulfur cell, which was introduced several years ago, makes use of liquid sodium as the negative electrode, a sodium-ion-conducting ceramic called beta-alumina as the electrolyte, and molten sulfur as the positive electrode reactant outside the tube.

Examination of failed zinc electrode from a lightweight zinc/nickel oxide battery.

The unique feature of this cell is the beta-alumina electrolyte, having the formula Na_2O-X Al_2O_3 where X is usually in the range 5 to 8. This ceramic (usually in the form of a closed-end tube) conducts sodium ions and acts as an otherwise impervious separator between the sodium metal inside the tube and the molten sulfur surrounding it (carbon felt conducts the current to the sulfur).

The products of the discharge reaction are sodium polysulfides which accumulate in the sulfur compartment. Problems with cracking of the beta-alumina and corrosion of cell cases by the sulfur and polysulfides have prevented rapid development of this cell. These difficul-

candidate batteries for electric vehicle propulsion

system	cell voltage	theor. W-h/kg	status W-h/kg[a]	status W/kg[b]	status cycle life[c]	projection W-h/kg[a]	projection W/kg[b]	projection cycle life[c]	year[d]
$Pb/H_2SO_4/PbO_2$	2.1	175	20-40	50-100	300+	40-50	150-250	500+	1977
Zn/KOH/NiOOH	1.7	326	50-65	100-200	100+	70-90	200-300	500+	1978
Fe/KOH/NiOOH	1.4	267	30-45	50-100	500+	45-50	100-200	1000+	1978
Fe/KOH/Air	1.2	720	90	30	200	120	50	300	1978
$Zn/ZnCl_2/Cl_2$	2.1	825	65	60	<100	110	100	500	1979
$Na/Na_2O\cdot X\ Al_2O_3/S$	2.1	763	80	150	1000+*	170-190	150-200	1000+	1985
$Li/LiCl$-KCl/FeS_2	2.3	1300	155	50	1000+*	200-220	150-200	1000+	1985

a. Specific energy at 10 W/kg
b. Peak specific power or maximum recommended specific power.
c. Cycle life for deep discharge (>60%).
d. Estimated date for initial availability at projected performance.
* These cycle lives are representative values for laboratory cells and have not necessarily been demonstrated with lightweight cells.

NEWS RELEASE

FROM: Lieberman-Harrison, Inc.
880 Third Avenue
New York, NY 10022
Contact: Alfred E. Connell
Phone: (212) 751-2820

FOR: Lead Industries Association, Inc.
Contact: Philip E. Robinson
Phone: (212) 679-6020

LIA-9/75

WHY ELECTRIC DELIVERY TRUCKS

Despite increased technology and market development of electric passenger cars, a number of factors will limit their use in the immediate future. The reason?

As yet there are no nationwide charging/changing stations, for electric passenger vehicles as there are gasoline filling stations, most of them with automotive repair facilities, for internal combustion vehicles.

Despite such factors that will, for the immediate future, limit the use of electric passenger cars, there are a number of reasons why the time is "now" for the introduction of fleets of electric work and transportation vehicles for use in commerce, business and industry:

(1) Most fleet-size truck operations already have one or more maintenance facilities and trained personnel. Thus, it would be relatively easy to train personnel in the operational maintenance of electrics;

(2) battery and electrical maintenance are an inherent part of many of the large-size truck fleet maintenance facilities. Therefore, most fleet operators can introduce electrics into their operational maintenance schedules with comparative ease after purchasing charging equipment, electrical repair tools

and training personnel to do the job;

(3) since electrics have far fewer parts to replace, inventory of replacement parts and components can be decreased; and

(4) most fleets operating in commercial service such as retail/ wholesale deliveries, food transportation and the service industries primarily operate in closed-loop service that involves short-haul, multiple-stop, pickup and delivery or personnel transport. For example, in New York and New Jersey, trucks used for wholesale and retail trade average approximately 15 miles in completing their rounds.

Another important reason the use of battery-powered electric work and transportation vehicles is expected to grow is the fact that manufacturers of such vehicles are establishing a network of service and distribution centers in all major metropolitan areas served by lightweight truck fleets. Most of this work is currently being accomplished through distributors specializing in battery powered materials handling equipment. Thus, they already have one of the most essential elements of a successful electric vehicle distributor -- trained battery and electric motor maintenance and repair specialists.

There are four fleet areas that represent a market potential for lightweight electric trucks since they involve a large percentage of short-range operations -- Wholesale/Retail, Services, For Hire and Utilities. The estimated total number of light trucks operating within these areas is 2,318,050, while the estimated local range of these trucks totals 1,432,697 miles.

The following fleet sizes are typical of fleets that have the biggest percentage of ther vehicles engaged in lightweight truck, short-range operations:

Utilities:	AT&T/Bell Telephone -- 140,000 vehicles
	Pacific Gas & Electric -- 2,000 vehicles
Services:	RCA -- 3,000 vehicles
	Singer -- 2,700 vehicles
	United Parcel -- 25,000 vehicles
Wholesale/ Retail:	Borden's -- 2,000 vehicles
	Safeway Stores -- 2,000 vehicles

12975

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Statement for the Record of

Dr. Harrison H. Schmitt
Assistant Administrator for Energy Programs
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Concerning

STATEMENT ON H.R. 5470
Electric Vehicle Research, Development
and Demonstration Act of 1975

I appreciate the opportunity to comment on the legislation introduced which would authorize in the Energy Research and Development Administration (ERDA) a Federal program of research, development and demonstration design, promote electric vehicle technologies and to demonstrate the commercial feasibility of electric vehicles.

The National Aeronautics and Space Administration (NASA) has been interested in electric vehicle development for a very long time. This interest emanates from our long and, we believe, successful association with space power and to some extent space propulsion techniques. In particular, the experience we have obtained and the capabilities which have been developed in the areas of batteries, power conditioning systems, electric motors, materials, vehicle designs including aerodynamics and overall systems analysis have potential contributions in the electric vehicle areas.

It may be that our interest in this area is most evident by the fact that we are in the final review stages of a comprehensive [illegible] development plan for electric vehicles [illegible] to [illegible] within the next two to three weeks. We are also currently funding a small test or possibly it could be considered demonstration, of the nickel [illegible]. Each of these activities represent a relatively significant investment by NASA of their experienced manpower in this critical and, we believe, extremely important area.

In our view, the objectives of H.R. 5470 are commendable and most certainly should be supported. However, we must emphasize that we believe the stimulation of the type of [illegible] demonstration and the very short periods of time allowed to achieve these demonstrations are premature and will result in counter-productive activity. [illegible] for two primary standpoints.

1. The research and advanced technology that is needed to assure successful demonstration will be compromised by producing the demonstration vehicles required by the Bill.

2. Because these vehicles will be, we believe, considered unacceptable by the general public and because they will not have the reliability, range, performance or first cost necessary for a viable commercial unit, they may well create an image in the public mind that electric vehicles are not useful and should be avoided.

[illegible]

[illegible]

[illegible] the introduction of electric vehicles into commercial utilization.

[illegible] to date in attempting to define a comprehensive program development plan for electric vehicles, what is most urgently needed at this point in time is congressional support of the ERDA electric vehicle activity over a rational period of time. I would at this point define a rational time as being approximately 10 years in duration if we are in fact to achieve the potential which exists in electric vehicles.

We currently envision the electric vechile program as having three specific steps.

A. Development of a preprototype vehicle to be available in three to four years and have a 50-60 mile range.

B. Develop a hundred mile range electric vehicle within 5-6 years using nickel zinc or possibly nickel iron batteries.

C. Develop an advanced electric vehicle within 8-10 years which would have a 200 mile range, using [illegible] storage systems now in various stages of research.

I should note we envision these development vehicles as being an urban vehicle and not one which would compete with what we have all known as the highway cruiser which is necessary for a successful, American family vacation or any long distance highway travel.

NASA would recommend that $200 to $250 Million be made available over an approximate 10 year period to systematically advance the required technology and the industry infrastructure so that viable electric vehicle demonstration could be achieved within the time frame I have indicated.

It is important to recognize that the correct design of an electric vehicle is not merely finding batteries, putting them in an existing chassis frame and connecting an electric motor to the wheels. For an electric vehicle to be a viable, commercial activity, (here I would define viable as a production line which could profitably sustain itself by delivering at least 10's of thousands of vehicles over a several year period) it is of course required that a very large number of urban residents believe that such a vehicle fits their economic situation and is a useful adjunct to their way of life.

Additionally, it must be possible to supply, service and recharge these vehicles within the transportation and power structure of at least the major urban areas, if not the entire Nation.

In conclusion, I would like to reiterate our support of the objectives of H.R. 5470. We believe that competently designed electric vehicles will become a viable part of the Nation's urban transportation system within the relatively near future. We feel that the research technology and demonstration of these vehicles is an important aspect of the national energy research and development planning. We know that the Energy Research and Development Administration is attempting to proceed along this path as rapidly as possible and we urge the Congress to support the ERDA activities over the approximately 10 year period of time which will be required to achieve appropriate research, development and demonstration in this vital activity.

June 11, 1975

Mr. Lloyd Curry
Chief Counsel
Energy Research, Development and
Demonstration Subcommittee
B-374 Rayburn Office Building
Washington, DC 20515

Dear Mr. Curry:

My name is William H. Shafer. I live at 308 South East Avenue in Oak Park, Illinois. I would like to submit the following observations on House Resolution 5470, a Bill authorizing ERDA to conduct a program of research, development, and commercial feasibility demonstration for electric vehicles. Please make this a part of the hearing record.

I am a graduate electrical engineer with a BS from Iowa State University in 1948. Since the graduation I have been employed in various technical, economic, and supervisory positions by Commonwealth Edison Company, an electrical utility serving about 2-3/4 million customers in the northern third of Illinois.

For the past six years I have closely followed electric vehicle developments, beginning with a paper presented at the first Electric Vehicle Symposium. I was chairman at three sessions (Passenger Cars, Commercial Vehicles, Buses and other On-The-Road) at the third Symposium. I am familiar with the work of many companies and individuals in the field of electric vehicle development. My position with a major electric utility has enabled me to have a broad look at various electric vehicle developments.

I fully support the findings stated in Section 2 of HR 5470. I also believe that the policy and goals stated in Section 3 are desirable.

To attain the stated goals, I believe that Section 6 should specifically direct the Administrator to include active participation of electric utility companies in determining overall system design. The design must take into account capability and economics of existing power systems.

I would like to cite two examples from my experience in support of this belief. Knowledge of electric power system characteristics and distribution systems, including customer wiring, has been freely provided, by me, to several electric vehicle developers. The maximum electrical demand that can be economically supplied from typical existing, single-family, residential wiring is 6-8 Kilowatts. This load would be connected to a 230-volt, 30 or 50 amp., single-phase branch circuit. If the electric vehicle system is designed to require a larger single-phase or three-phase supply for the charger, both the utility and homeowner would require significant expenditures to change existing utility and customer wiring. Such expenditures could be $1000 or more. This would not meet the intent of HR 5470 to encourage electric vehicle commercial development.

As a second example, the probable private electric auto use pattern would be daytime vehicle use with nighttime charging. The battery charging design should take into account the characteristics of utility power system loads. It is during the nighttime hours that a utility's most efficient generating units (including nuclear) can be best employed for electric vehicle battery charging. If the battery charging period is only 2-3 hours, a nighttime valley in the utility load curve will remain. Electric vehicle system design must attempt to spread charging loads over the full nighttime period to realize energy advantages stated in Section 2 (12) yet still not compromise vehicle usefulness for the consumer.

I recommend that Section 6 be restated as: "The Administrator, acting through appropriate agencies and contractors including electric utility companies, shall initiate and provide for the conduct of research and development in areas related to electric vehicles, including -----." Addition of the underlined phrase will leave no doubt that utility companies responsible for electric energy supply are to be participants. This will insure an optimum overall electrical system design.

I believe that Section 7 (b) should be eliminated. Experience over the last half-dozen years has indicated it is not economically feasible to take a standard automobile--remove the engine, gas tank and other engine-related parts, add value to the remainder by installing electric components, and expect to successfully sell the finished electric conversion in competition with the original product. Companies that have put electric propulsion systems into conventional automobiles have found, in small scale production, the final product is extremely costly. A standard auto selling in the $4-6000 range ends up converted to electric drive and selling for $10-15,000. Even in larger scale production, the converted car will probably be too costly to gain wide commercial acceptance. This seems not to carry out the requirements of Section 3.

I believe that quantity production is the essential ingredient in implementing requirements of Section 3. Significant numbers as defined by Section 4 (4) of the Act should not be limited to 5,000 vehicles. To attain the necessary mass-production economy on scale, a realistic number would be ten times this amount. Electrical components in small quantities are costly. For example, a 25 HP electric motor, which is required to achieve reasonable acceleration and top speed performance, will cost almost $1,000 in single-unit quantities. The same motor built using mass-production techniques will be about $200 in annual production quantities of 50,000. Other components have similar pricing characteristics. Production quantities as noted above can realistically only be undertaken by companies already experienced in vehicle and component production.

I believe the Committee and Congress can benefit from a study of the Japanese approach to electric vehicle development. By spending a modest sum of $14-million over the past few years, the Japanese Ministry of International and Trade Industry (MITI) has contracted with existing Japanese automobile producers for the development of five different types of electric vehicles. The attached Exhibit A outlines the program and vehicles being developed. I believe the Committee should consider a similar approach.

I believe the Federal Government can be instrumental in promoting electric vehicle commercial introduction. Without the assistance provided by this Act, I believe there is a very real possibility that imported electric vehicles developed abroad, may supply a significant portion of the U. S. market before present American suppliers can develop a competing domestic product. This would have an adverse balance-of-payments effect. It seems to me that the U. S. should continue its recognized leadership by developing electric vehicles not only for domestic but also for world-wide sale.

I urge consideration of the changes I have proposed, and enactment of legislation to meet the findings, policy and goals of HR 5470.

William H. Shafer
William H. Shafer

WHS/kea

cc: Henry J. Hyde
Rep. 6th Dist., Illinois

MOTOROLA INC. *Automotive Products Division*

June 18, 1975

The Honorable Mike McCormack
Chairman, Sub-Committee on Energy
Research, Development & Demonstration
Committee on Science and Technology
U. S. House of Representatives
Washington, D. C. 20515

Dear Mr. Chairman:

Motorola, Inc. supports a governmental policy of promoting basic research on electric vehicle batteries, controls and motors. Motorola also supports conducting demonstrations of the feasibility of commercial electric vehicles; ascertaining consumer needs and desires so as to match the design of electric vehicles to their potential market; and ascertaining the long-term changes in road design, urban planning, traffic management, maintenance facilities, utility rate structures, and tax policies which are needed to facilitate the manufacture and use of electric vehicles.

Although three years is a short cycle time for the development of demonstration hardware, it is not impossible with today's technology. However, this short cycle emphasizes the need to utilize existing theoretical vehicle system technology as documented at the 3rd International Electric Vehicle Symposium. Thus, Motorola would encourage de-emphasis of developing theory for optimal overall electric vehicle design - and encourage emphasis on confirming the optimization models currently available.

Motorola does not believe that electric vehicles will rapidly replace current vehicles but electric vehicles are practical today for many applications. They conserve natural resources (batteries are recycleable) and any battery technology breakthrus will significantly widen the market. Thus, except for the minor shift in emphasis noted, Motorola, Inc. completely supports the spirit and substance of the proposed legislation.

Sincerely yours,

Robert J. Solem
Vice President & Deputy
General Manager
Automotive Products Division

RJS:nr

STATEMENT

****

May 28, 1975

Mr. Antonine Lafata Sottile
Ph. Doctor of
Electro-mechanical Engineering
P. O. Box 28292
Washington, D. C. 20005

REF:
WAGON EUREKA
Electric Vehicle
****

Honorable Mr. MIKE Mc CORMACK
****
Chairman SubCommittee on ENERGY
RESEARCH, DEVELOPMENT and DEMONSTRATION
Committee on Science and Technology
HOUSE OF REPRESENTATIVES RHOB
Washington, D. C. 20515

cc: Mr. OLIN E. TEAGUE
Chairman of the Committee
on Science & Technology

Dear Mr. Mc CORMACK:

Having had opportunity to review the 94th Congress' Bill H.R. 5470 on the "ELECTRIC VEHICLE RESEARCH, DEVELOPMENT and DEMONSTRATION ACT of 1975" and hearings on the subject having been scheduled for next June, I would like to appear before your SubCommittee and to present my views and related documentation, concerning an electric vehicle I devised: WAGON EUREKA.

I'm Mr. Antonine Lafata Sottile — Ph. Doctor of Electro-mechanical Engineering. My professional resumé is attached to this documentation.

My proposition requires at least two different sizes of WAGON EUREKA:

BUS SIZE — to be employed in Bus networks and commercial services and successively in the new kind of subway I outlined: LEANWAY.

COMPACT SIZE — to be employed as ordinary passenger vehicles in substitution of the internal-combustion-vehicles in the existing roads and successively in the new roads I outlined: At.La.S utilities.

Both projects: LEANWAY and At.La.S are characterized by a continuous alternance of steep downgrades and steep upgrades to accelerate and decelerate vehicles by exploiting GRAVITY.

It is a first step and a historical one, by which roads cease that inert role they have assumed in communications from ancient times (for example: Via Flaminia, Via Salaria, Via Aurelia in Rome) with motion relying exclusively on horse-animals or horse-powers as vehicle-agents.

The expansion of the electro-magnetic suspension-propulsion could complete the steps to assure to roads as well as to tracks entirely the propulsive-function and transfer to vehicles an inert role.

It is necessary to note that an electro-magnetic suspension-propulsion from the ground is too expensive, requiring costly equipment all-the-way, for miles and miles.

The electro-magnetic suspension-propulsion from the vehicle requires alike a costly and heavy equipment in each vehicle with heavy losses in the energy transfer from feeder-lines to high speed vehicles.
A practical solution would consist in the exploitation of downgrade (say for 90% of each alternance) and to utilize electro-magnetic suspension-propulsion FROM-THE-GROUND in the terminal steep upgrade of each alternance until surfacing again (say for 10%).

At this point it is necessary to quote a 1972 Report from the Underground Construction Research Council of ASCE, sponsored by National Science Foundation, entitled "The use of underground space to achieve national goals."

After having cited "the tremendous negative effects associated with surface construction" the Report consideres eight groups of civil works functions, convenient for underground: for the immediate future, underground location for all new urban freeways and electrical energy distribution systems would be the most feasible.

The Report estimates that by undergrounding 5,000 miles of urban freeways and two-thirds of a million miles of electrical energy distribution lines, at the end of 10 years the total 15.5 billion dollars required by the work, would have been released (through benefits) and a $6 billion annual economic savings would accrue thereafter.

The above reason, apart from problems of deplete fuel supplies, pollution, noise etc. stresses still more the necessity of eliminating from traffic internal-combustion vehicles inadapt in tunnel traffic and emphasizes the necessity of the WAGON EUREKA, ELECTRIC VEHICLE. Also by building these underground roads accordingly to At.La.S and LEANWAY outlines we may save and recuperate energy by exploiting gravity.

The attached documentation includes few pages of both projects, but last year I delivered to the Library of Congress a complete copy of the Leanway project. In the included pages 31, 33 the Wagon Eureka is outlined with its fitness to recuperate energy and to maintain its floor-deck permanently at level for a better comfort of passengers. Also stronger positive and negative accelerations (easily achieved through steeper grades) would be accepted.

A cheap almost weightless LASER-gyroscope could appreciate changes of levelness of the order of a nanometer in a nanosecond and command an appropriate counterbalancing mechanism. Should flywheels be installed in the wagon as recuperators-accumulators of energy, the levelness could be assured simply by the gyroscopic stabilizing property of flywheels. A kind of spherical bearing could allow free rotation in all directions to the wagon's body over the underframe.

Title page and page 18 summarize the distinction between uni-vehicle Innercity and pluri-vehicle Intercity Leanway, requiring the wagon Eureka: cheap, clean, efficient subway with Stops at surface to be expanded everywhere to replace all Bus lines now served by internal combustion vehicles and to eliminate from traffic because of its ubiquity a lot of conventional automobiles and trucks.

The expansion in the roads of the Wagon Eureka in a timely way will complete the process to free all traffic from internal combustion vehicles.

Page 1 and page 5 summarily outline the At.La.S urbanization and the At.La.S interchange respectively, conditioned to the operation of the Wagon Eureka—electric vehicle.

So new kinds of vehicles, of roads, of tracks, of urbanization will converge coherently to the purpose of utilizing every fraction of "g" (gravity acceleration): This not requiring necessarily major construction expenses, only requiring to build differently, not excluding the advantage of future cheap tunnels.

WAGON EUREKA — ELECTRIC VEHICLE

****

COMPACT SIZE and BUS SIZE

APT — for existing roads, to replace and eliminate from traffic "internal-combustion vehicles"

APT — for future surface-or-tunnel roads At.La.S utilities and for future LEANWAY system of subway, both roads and tracks unidirectional consisting of successive alternances of steep downgrades and upgrades to exploit GRAVITY.

EQUIPPED — by ELECTRO-MAGNETIC suspension-propulsion FROM-THE-GROUND in the terminal steep upgrade of each alternance until surfacing again.

EQUIPPED — by FLYWHEELS, as gyroscopic stabilizers of the wagon-floor-deck permanent levelness (in spite of steep downgrades and upgrades continuous succession), and as accumulators-recuperators of energy.

COMPLEMENTED — during the intermediate phase of development by a TROLLEY for intermittent pick-up of energy from suspended feeder-lines.

COMPLEMENTED — by SOLAR CELLS and other kind cells, and by means to recuperate and store energy.

ADVANTAGES of the WAGON EUREKA: possibility to reach high speeds with almost motorless vehicles.

Lower requirements of installation and operation.

High capacity of energy savings.

In conclusion, as concerning the Bill H.R. 5470, I must emphasize:

— Opportunity to quote in the Bill: "SOLAR CELLS" since vehicles could recharge while stationing or running under sunshine.

— Opportunity to quote in the Bill: "FLYWHEELS" to which the present "state of the art" assure a ten-fold capacity of accumulating energy than the lead-acid batteries for unity of weight, with higher regenerative efficiency, higher time rates of charging and discharging energy and useful gyroscopic stabilizing properties.

— Opportunity to quote in the Bill: "TROLLEY" as intermediate phase. For the immediate, a network of trolleybuses could eliminate the presently operating internal combustion buses. Passenger electric vehicles and electric trucks could also achieve a greater autonomy in the existing highways should in the right lanes of these highways appropriate suspended feeder-lines be provided for intermittent pickup of energy at lower speeds.

— Opportunity to quote in the Bill: "ELECTRO-MAGNETIC SUSPENSION PROPULSION" as definitive long-range phase to which all efforts must be directed to perfect the land transportation as outlined by Leanway and At.La.S projects and by the Wagon Eureka.

— Opportunity to quote in the Bill: "GRAVITY" with vehicles fit to exploit this free, clean, inexhaustable form of energy. In fact, the production and transformation of electric power occurs at high efficiency but is not losses-free and is conditioned to the availability of energy basic supplies and related problems.

During 1973 in the United States, about 100 million automobiles and little trucks required over 2 billion barrels of gasoline corresponding to about 3 trillion KWh. Due to the low 10% Otto-cycle efficiency, 2.7 trillion KWh were discharged in the atmosphere as direct pollution. From the remaining KWh (about 0.3 trillion) suited for traction, only a fraction was utilized to overcome drag and friction while a great lot also was wasted in brakes and in idle-running-times at stop lights.

So time-phases outlined in the Bill H.R. 5470 for the purpose to replace and eliminate from traffic internal-combustion vehicles should be accelerated and the required budgets multiplied.

Sure of your high consideration, dear Mr. Mc Cormack, as well as of the high consideration of the Committee, please accept my respects.

ANTONINE LAFATA SOTTILE

Attachments:
1. Resumé
2. Title Page LEANWAY — A Leaning Subway
3. Page 18 Innercity and Intercity Leanway
4. Page 1 At.La.S Urbanization with uninterrupted traffic
5. Page 5 At.La.S Interchange
6. Page 31 Wagon Eureka in downgrade and upgrade
7. Page 33 Wagon Eureka frontal view

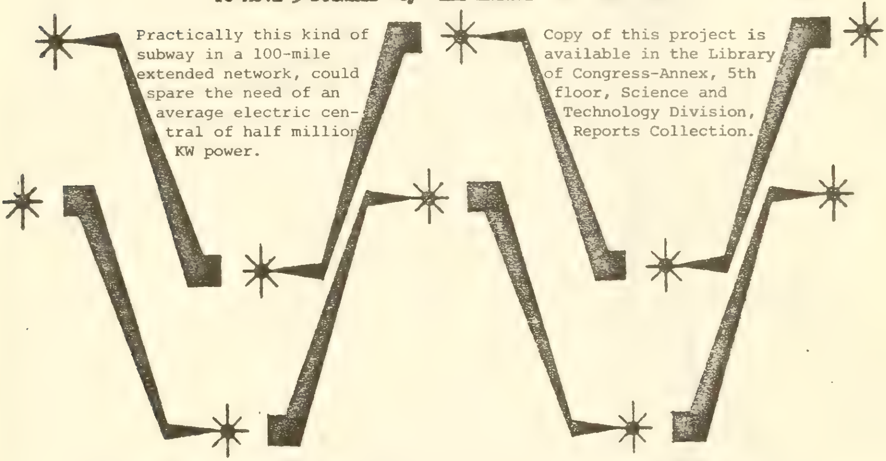
LEANWAY

A LEANING SUBWAY

LEANWAY's MOTTO

TO BUILD and TO OPERATE 2 SUBWAYS by THE BUDGET of ONLY ONE

TO MOVE 5 SUBWAYS by THE ENERGY of ONLY ONE



Practically this kind of subway in a 100-mile extended network, could spare the need of an average electric central of half million KW power.

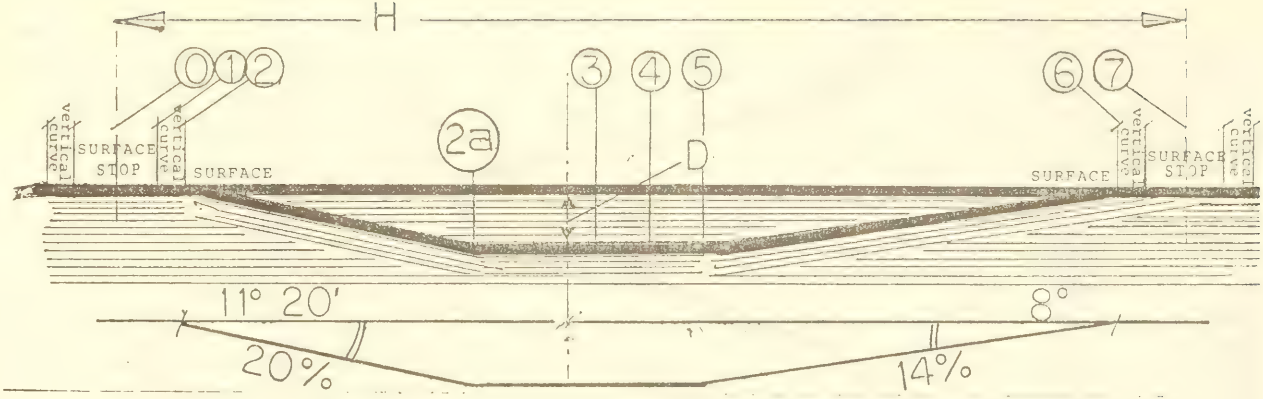
Copy of this project is available in the Library of Congress-Annex, 5th floor, Science and Technology Division, Reports Collection.

Complementary notes summarize the "state of the art" on Tunneling, Linear Induction Motor, Electro-magnetic suspension-propulsion. Superconducting electro-magnet.

1974

Leaflets published and free distributed by the Washington Metropolitan Area Transit Authority are included in order to give a direct, in-real-time proof of how complicated, laborious, expensive is the construction of a classical Metro, emphasizing the need to adopt the Leanway system.

PROJECT
by
Mr ANTONINE LAFATA SOTTILE
Ph DOCTOR OF ENGINEERING



NOTE: The assumed rates of upgrade and downgrade are provisory: employed only to outline reference data of accelerations, speeds, times, capacity, deepness, etc.

INNERCITY LEANWAY (Inside the city subway)

Length of STOP (Station) = 40 m.
Accommodating only 1 Wagon Eureka (Subway car)
Maximum capacity of 1 wagon (2 segments)
28 seated + 174 standing = 202 commuters, or
28 seated + 50 standing = 78 commuters
+ 4 automobiles
Maximum capacity each way--(only 1 wagon each
20 seconds) 36,360 commuters/hr--without autos

Horizontal Distance H = m.	400	500	600	700	800
Effective Distance E = m.	403.2	504.2	605.3	706.4	807.6
Maximum Deepenss D = m.	17.9	24.5	31.1	37.7	44.3
Top speed at point (4) = Km/h	77.04	87.70	97.27	106.02	114.04
end of acceleration and Start of deceleration = mile/h	48.10	54.80	60.79	66.26	71.28
Time from point (0) depart to point (7) arrival(seconds) =	41"94	48"04	50"00	53"64	56"90

INTERCITY LEANWAY (Between cities subway)

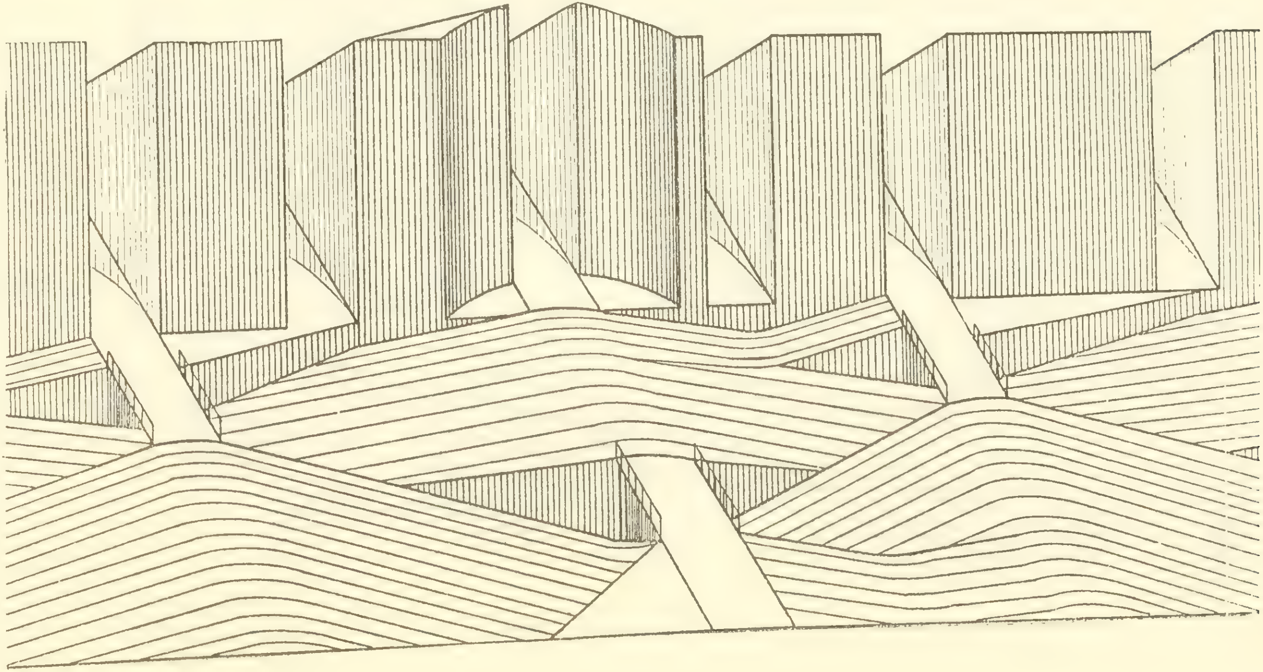
Length of a STOP (station) = 140 m.
Accommodating a 7-wagon-train
Maximum capacity each way--(a train each
90 seconds headway)
56,560 commuters/hr without autos, or
21,840 commuters/hr with 1,120 autos,

Horizontal Distance H = m.	1,200	2,200	3,200	4,200	5,200
Effective Distance E = m.	1,209	2,221.7	3,233.7	4,245.6	5,257.
Maximum Deepness D = m.	57	127.8	196.6	266.2	335.
Top speed at point (4) end of acceleration = Km/h	134.5	191.3	234.3	270.7	302.
and Start of deceleration = mile/h	84.1	119.5	146.4	169.2	189.
Time from point (0) depart to point (7) arrival(seconds) =	71"22	92"60	110"22	123"68	136"

ALTERNANCE LANES SYSTEM WITH IMPROVED UNINTERRUPTED TRAFFIC

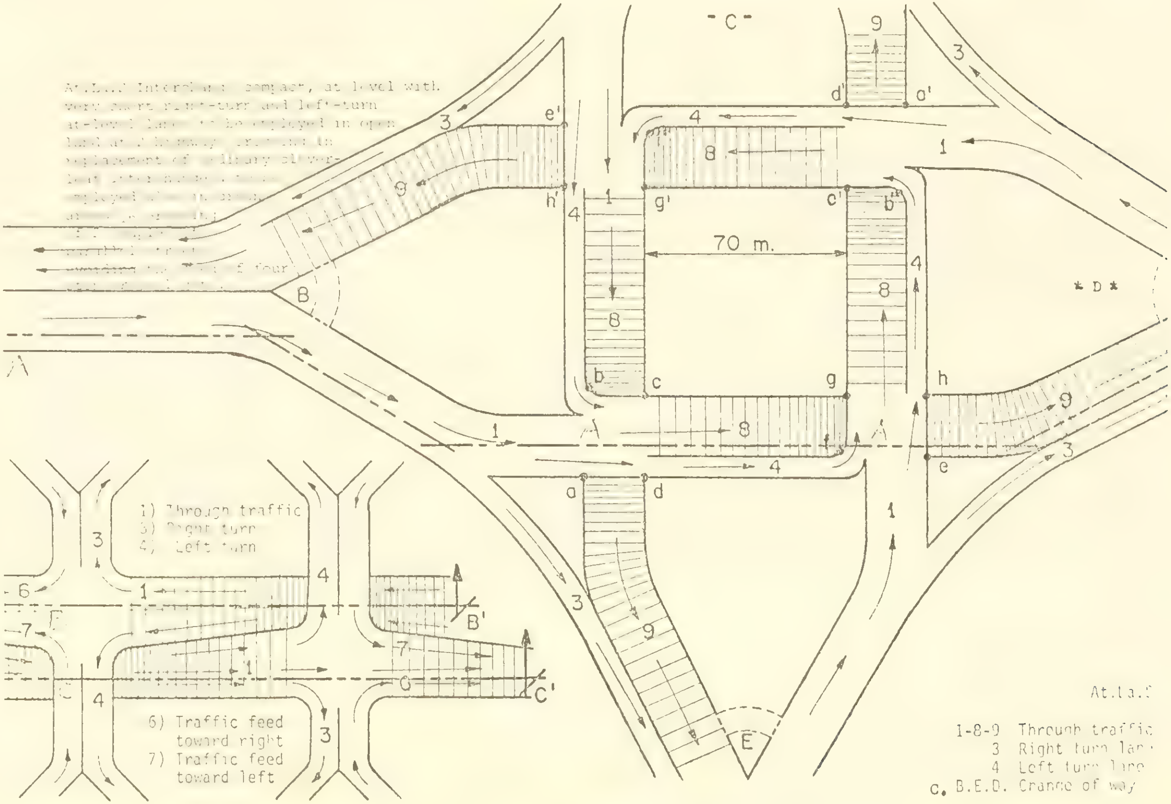
At.La.S - 1968 - Project by Mr. Antonine Lafata Sottile

Utilization of the systematical opposition of phase between both contrary ways in order to settle between these a difference of elevation, that allows alternatively at each intersection the left-turn to the vehicles of a way, crossing over the contrary way, by means of a bridge: So the left-turn may be operated easily and uninterruptedly. The alternance Avenue constitutes an ordinary freeway, having eliminated the freeway inconveniences: impossibility of left-turning movement and cut of a metropolitan area in 2 each-other-incommunicable stripes. By elimination of every signal-control, buying and maintain of complicated signal installations no more will be necessary; the traffic-capacity of the Avenue at least will come out doubled, while time, materials and fuel will be economized by exploiting gravity and recuperating energy.



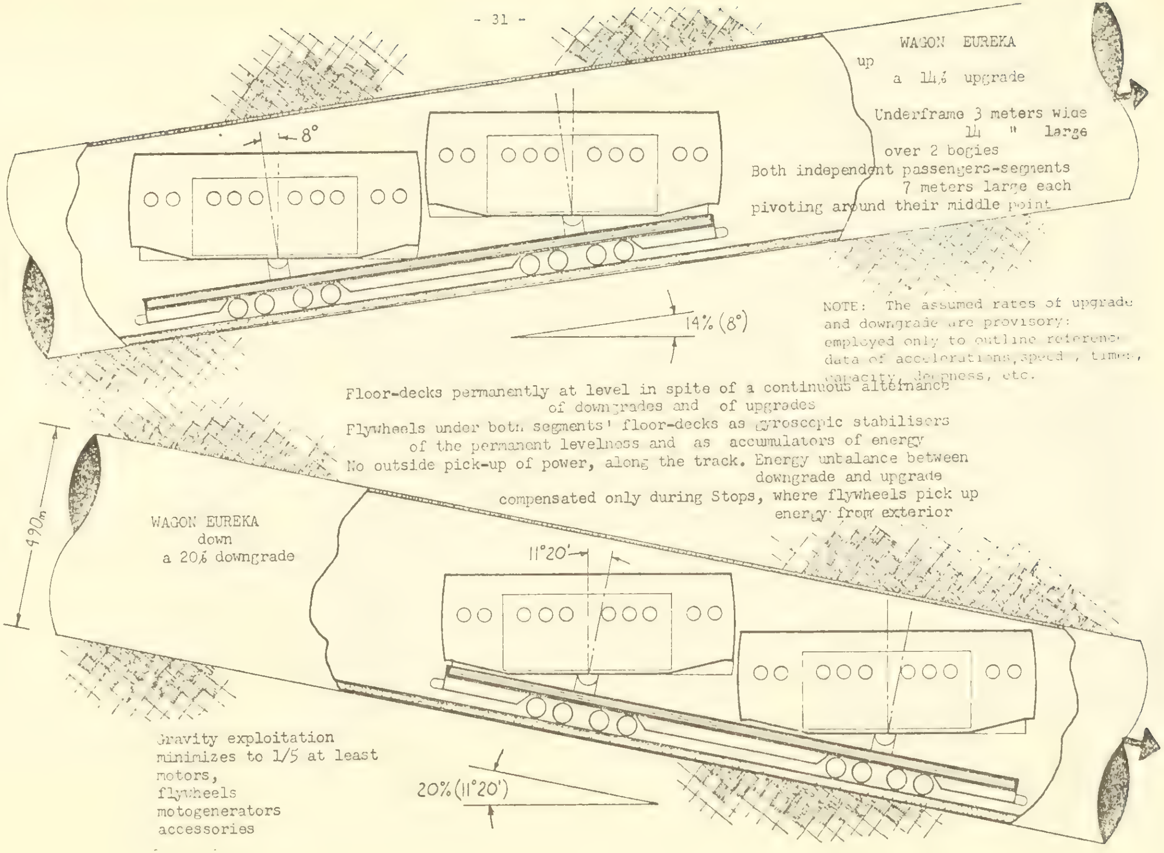
5)

At.La.I Interchange: compact, at level with very short right-turn and left-turn at-level lanes to be employed in open land and highway crossings in replacement of ordinary clover-leaf interchanges. [illegible] employed [illegible] of four [illegible]



ALTERNANCE JUNCTION

ALTERNANCE INTERCHANGE



WAGON EUREKA
up
a 14% upgrade

Underframe 3 meters wide
14 " large
over 2 bogies
Both independent passengers-segments
7 meters large each
pivoting around their middle point

NOTE: The assumed rates of upgrade and downgrade are provisory: employed only to outline reference data of accelerations, speed, times, capacity, deepness, etc.

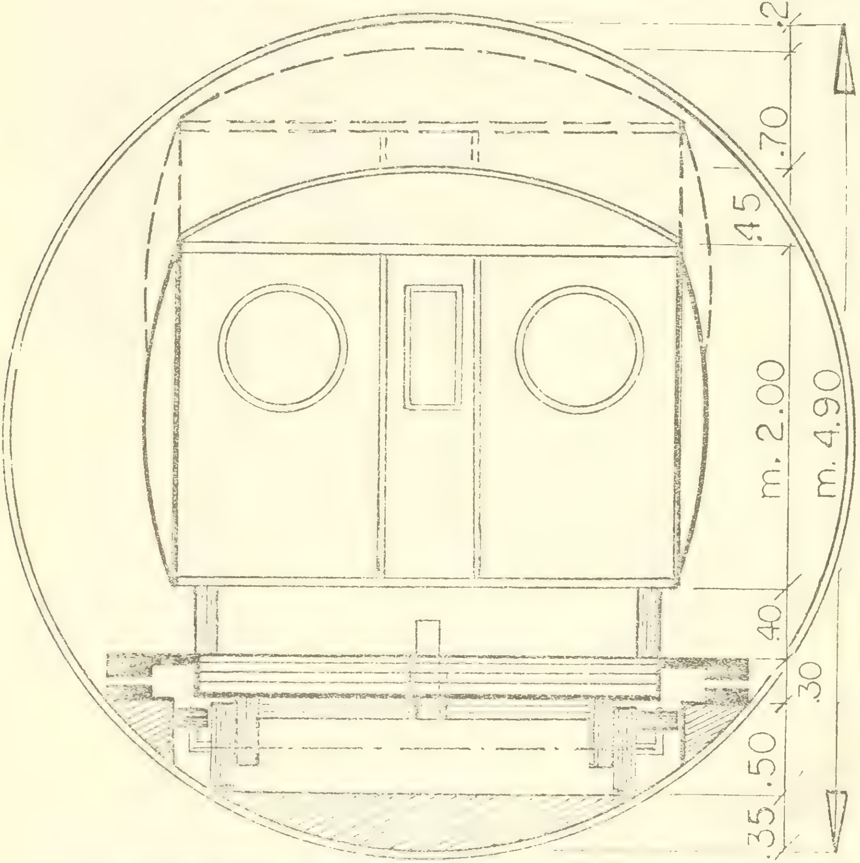
Floor-decks permanently at level in spite of a continuous altemance
of downgrades and of upgrades
Flywheels under both segments' floor-decks as gyroscopic stabilisers
of the permanent levelness and as accumulators of energy
No outside pick-up of power, along the track. Energy unbalance between
downgrade and upgrade
compensated only during Stops, where flywheels pick up
energy from exterior

WAGON EUREKA
down
a 20% downgrade

Gravity exploitation
minimizes to 1/5 at least
motors,
flywheels
motogenerators
accessories

[illegible] frontal view

The dashed line represents the upper position of the [illegible], at level, with the underframe parallel to the [illegible] grade of the track.



Medium side and lower clearance, [illegible] guide wheels and electro-magnetic suspension outlines.

JUN 6 REC'D

MECHANICAL TECHNOLOGY INCORPORATED
LATHAM, NEW YORK
12110

BENO STERNLICHT
BOARD CHAIRMAN

MTI

June 3, 1975

Dr. Thomas Moss
Technical Consultant to Mr. Brown
U. S. House of Representatives
Washington, D. C. 20515

Dear Dr. Moss:

Per your request, I am submitting a written statement on H.R. 6198.

The sponsors of Bill H. R. 6198 (originally H.R. 5470) on electric vehicles should be complimented for initialing the above bill. We all recognize that the health of our national economy is largely dependent on the automotive industry. Some of us have recognized the potential of the electric vehicle from a favorable balance of trade, conservation of liquid fuel, improved overall efficiency, greatly reduced emissions and noise, etc.

For some time I have been a strong advocate of the hybrid (heat engine/electric) and all electric vehicles as a highly viable system that can fulfill many of our required transportation missions (urban travel, etc.) and therefore, can represent a large share of future automobile markets.

I have expressed my views first, in a Product Engineering article published in February, 1974, expanded in an ASME paper #74-DGP-16, and later published in Mechanical Engineering in November, 1974. (This paper has received ASME honors in 1975) Excerpts from these articles are attached.

It is important to point out that the automotive industry has been under severe social, regulatory and economic pressure over the last decade. (See Fig. 1) All of these issues are additive and have put the automotive industry in a precarious position. The next likely issue will be natural resources; this will be especially true if wrong materials are selected for electric vehicles. (See Figs. 2 and 3, and Table I)

Most of today's batteries use lead and some of the advanced batteries use nickel. Both of these materials are in limited world supply and very little is found in the U.S. Already the automotive industry consumes very large percentages of these materials. Therefore, these materials are not viable for batteries in electric vehicles.

Batteries using zinc are also under development. While reserves for zinc are also limited in world supply, large quantities of zinc can be extracted out of sea water. Cost and electrical power availability are the only issues. These observations are cited only to point out that a balanced well conceived program in electric vehicles is necessary in order to make the electric vehicle a viable business and mode of transportation. Just a wrong material choice for batteries can make the program worthless.

I have been seriously concerned with the lack of R&D effort in our country in this field and in fact have warned the automobile industry that their business is threatened by electric vehicles manufactured by their competitors in Japan. We recognize the seriousness of the Japanese competition in mass produced products. They have recognized the potential of the electric vehicle and have for some time concentrated their R&D effort on this subject. The bill, therefore, provides incentive and acts as a catalyst in our country, for which it is to be commended.

I have, however, a very serious concern with one part of the proposed legislation. It centers on demonstration.

Demonstrations can have both positive and negative effects. A poor demonstration can have a major setback to a highly worthwhile endeavor. We all can cite many such examples. I feel that the proposed demonstration will have this effect.

My concern is based on personal knowledge of the present state of this technology, which is very limited and on the three years proposed which are much too short. The demonstration, therefore, will have to use poor components, which will undoubtedly result in poor overall performance and public acceptance. In addition, the R&D effort, which is very badly needed, will have to take second place to the demonstration program and this is also very dangerous. Demonstration overruns, resulting from problems, cost escalation, etc. will diminish the R&D effort. While I recognize the urgency and the value of demonstrations, we cannot easily make up for the lost time. It takes approximately nine months between conception and delivery; complex electromechanical systems, take an order of magnitude longer. Let's prevent abortion and also premature delivery which carries with it many unnecessary risks. The stakes are too high to take the proposed demonstration shortcut.

It is also very important that we extend our options to include hybrid systems. these systems offer considerable potential and provide us with more time for the transition from the heat engine to the all electric propulsion. It provides the following modes of operation:

. Heat engine propulsion for rural travel.
. Electric propulsion for urban travel.
. Heat engine and electric for acceleration.
. Electric for regenerative breaking.

In addition, it provides an excellent means for recharging of the battery, both during driving cycle and also where recharging facilities are not available.

With time, as batteries improve, the heat engine will require less power and in the limit, it will become zero and be eliminated. The progress in the battery field will dictate this transition.

I would, therefore, like to recommend that the bill be modified to greatly increase the chance of our success. This can be accomplished by extending the period of the demonstrations and insure a vigorous national R&D effort.

The act should call for appropriations not to exceed $750,000,000 over a period of ten years. The first four years should be devoted to R&D in three critical component areas; batteries, transmissions and controls, and to hybrid and electric vehicle designs and integration. The next three years should be devoted to the demonstration of the hybrid and electric vehicles and continued R&D effort towards second generation of electric vehicles. At the beginning of the seventh year, the second demonstration should be initiated. In this case, the primary focus should be on the all electric vehicle.

To achieve this, the following funds should be appropriated:

$ 30,000,000 for fiscal year 1976.
$ 40,000,000 for each of the three years: 1977, 1978 and 1979.
$100,000,000 for each of the six years: 1980, 1981, 1982, 1983, 1984 and 1985.

Any amount appropriated shall remain available until expended, and any amount authorized for a given year, but not appropriated, may be appropriated for the next fiscal year.

The Highway Vehicle Directorate of ERDA's organization is already set up to manage this program. They lack, however, the necessary funds and some additional staff to conduct a vigorous R&D program.

These modifications to the bill will greatly increase our chances of success. The bill will be responsive to our national need. It will act as a catalyst for a new automotive industry and to some extent spurt our lagging national economy.

Sincerely,

Beno Sternlicht

Beno Sternlicht
Technical Director

BS/bn
Encls.

Excerpts from article in Mechanical Engineering

1973 ...rmal Eff (...)	Fuel Economy[a] (FDC - miles/gal) Present (1973)	Fuel Economy[a] (FDC - miles/gal) Future (1980's)	Multifuel	Capable of Meeting 1976 Emissions Standards	1973 Noise Rating	Relative Engine Cost[b] (20% for all but standard ICE)	Reliability/Maintenance as Compared to ICE	Drivability as Compared to ICE	Critical Elements[c]	Short Term[d]	Long-Term[e]
10 avg	13 10	13 10	no no	no probably yes	high	1.0 1.6	good will be worse	good will be worse	none reactors and converters	2	
7	10	13	no	probably yes	high	1.2	will be worse	good	reactors converters seals		
10	10	13	?	yes	high	1.5	will be somewhat lower	good	none	1	
1	25	30	no	probably yes (smoke & odor)	somewhat higher	2.0	very good	worse	none	1	1
10	12	20	yes	probably yes	low	2.0	good	very good	high temperature turbine materials & regenerator		2
10	12	15	yes	yes	very low	1.8	good	very good	none with steam new fluids		
5	15	25	yes	yes	very low	2.0	good	very good	high temperature alloys for heater head seals controls		1
16		20-25	yes	probably yes	high	1.4	good	good	high temperature valve material		1
16		26[f]	yes	yes	very low	1.8	very good		high-density lightweight battery		1

[d] Short term defined as engines that are available today and could be put into mass production to ensure impact (10% of all operational automobiles on the road)
[e] Long term defined as engines that should be developed further so that one or maximum of two (internal or external combustion engine and electrical power plant) would make impact by year 2000
[f] Equivalent (0.4 kwh/mile)

In the selection process, various factors must be considered and trade-off studies must be conducted. In the opinion of the author, the factors listed in Table 4 should be assessed. Many of these factors were considered by the author in arriving at the short- and long-term selection presented in Table 5.

Table 5 presents a technology perspective and summarizes the short-term and long-term priorities. Note that this table adds two additional candidate power plants (the Warren engine and the electrical propulsion). On a long-range basis (impact in the 1990s) it gives five options. It is very doubtful whether more than two will materialize. This is because of the very large investment in tooling, plant, and education that would be required. [The U.S. automotive industry has in excess of $10 billion invested (1975 book value) in tooling alone for the Otto engine. The largest investment in tooling in a given year for the automotive industry as a whole was $2 billion.] Thus, the five power-plant options will have to be reduced to one or two. It is very likely that the electrical vehicle will be one of these and an engine system will be the other. It is interesting to point out that most of the engines identified here as having high priority are not the engines that the automotive industry has selected today. In fact, two of these options are being worked on by small R&D companies.

It is somewhat disturbing to note that practically every new engine has been conceived abroad. It was the Japanese Honda that sparked new U.S. interest in the stratified-charge engine. Today Japan, because of its integrated, governmentally supported R&D effort, is also way ahead of the U.S. in the development of the electrical vehicle, which could be the future competitor to our automotive industry.

It should be recognized that the time for new engine penetration is very long. Figs. 8 and 9 show the history for commercialization [3]. The automatic

Fig. 8 Commercialization history — major automotive products

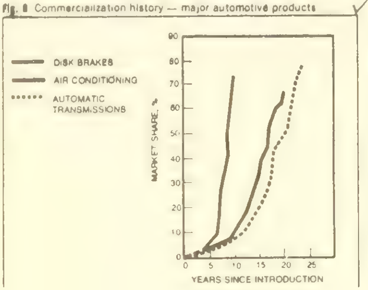
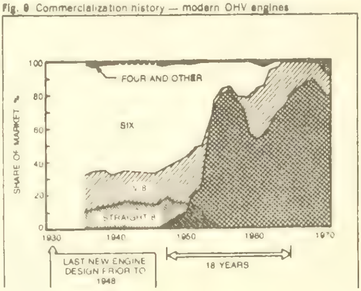


Fig. 9 Commercialization history — modern OHV engines



transmission took 20 years, air-conditioning 17 years, and the disk brakes seven years from successful introduction to a 50 percent market penetration ("50 percent market penetration" corresponds to about 10 percent of total cars on the road using the system.) The 50 percent penetration with the overhead valve engine took about six years.

In a recent EPA meeting, Ralph Cross, president of Cross Company, indicated that a changeover to a completely new engine would take 12.3 years based on present capacity of the transfer (automated manufacturing) machine industry. Another study [4] indicates that it would take about ten years (six years for preproduction and four years to full production). Thus, if technology readiness for the new engine system will only be available by 1980 and it takes about ten years for full production, the impact of the new power plants cannot occur until the early 1990s. With additional motivation and incentives, this period could possibly be shortened so that impact could be seen by the late 1980s.

Summary and Conclusions

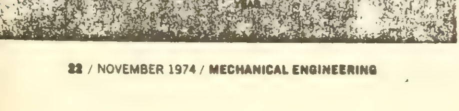
With the aid of some crystal ball gazing, the range of expected market penetration is shown in Fig. 10. In the near term, the stratified-charge engine looks potentially attractive, offering required low emissions without sacrifice in fuel economy. It does not add costly hang-on controls of questionable reliability, and it represents a relatively minor tooling change.

The catalytic converter will probably have a short history. Not only will it greatly increase cost and use materials that have to be imported, but also it is expected that its regular inspection and maintenance will bring its demise.

On a long-term basis, there are five candidates. It is expected that one of these will be the electric vehicle that will probably start making an impact in the late 1990s. The electrical vehicle may have its best application possibilities for urban travel, where the distances are relatively short and speeds are low. One can envision parking meters that also perform the recharging function. Hybrid (engine/electric) systems are also good candidates.

The other will be an engine probably with external combustion. The Stirling engine is the most likely candidate, although the diesel or the Warren engine show considerable promise at this time. It is too early to predict which of these has the greatest potential. Therefore, additional studies and development are necessary. The Warren engine is the newest and has had very little development conducted on it. There is, of course, a chance that another power plant may emerge that has far greater potential than the ones cited. This is very unlikely, for it generally takes many years (five to ten) between concept and demonstration of feasibility and acceptance by technical and management community. However, if technology proceeds far enough so that ceramic turbines are capable of operating at high turbine inlet temperature and can be manufactured at relatively low cost, then the gas turbine [12] may become a major contender.

Fig. 10 Range of expected market penetration.



The author does not believe that the Wankel, Rankine, or the gas turbine are likely to become automotive power plants with impact by the year 2000.

It is expected that the reciprocating piston engine will remain dominant at the turn of the century. However, it will probably change from internal to external combustion and will use various energy recovery systems.

Because of the many candidates and the various, often conflicting interactions, it is essential that a timely and effective process for screening be established. All the socioeconomic factors must be considered if one hopes to develop two viable automotive propulsion systems that will have impact by the year 2000.

Automobile manufacturers will undoubtedly continue to approach change with caution and will follow conservative introduction and commercialization strategies [3, 4, 13]. The socioeconomic requirements will play a much greater role in the selection of a power plant than they have ever played before.

References

1 "The National Energy Position," (one of a series of Shell papers on issues of major national concern), Shell Oil Co., Feb. 1973.

2 Task Flow Diagrams of the Advanced Power System Vehicle Program of EPA, July 9, 1970.

3 Richardson, R. W., "Automotive Engines for the 1980's," *Abstracted Automotive Engineering*, Eaton Corp., Oct. 1973.

4 "Economic Impact of Mass Production of Alternative Low Emissions Automotive Power Systems," Department of Transportation Final Report under Contract DOT-OS-20008 ES, Mar. 6, 1973.

5 "An Action Plan," prepared by AAPS–EPA, July 1972.

6 Sternlicht, B., "The Role That NASA and The Space Technology Community Can Play in the Energy Crisis," (statement prepared for Subcommittee on Space Science and Application and the Subcommittee on Energy, Committee on Science and Astronautics, House of Representatives, as requested by Congressmen James W. Symington and M. McCormack), July 1973.

7 Brogan, J. J., "Alternative Powerplants," SAE Paper 730519, 1973.

8 "An Evaluation of the Stratified Charge Engine Concept," EPA Report APTD-1356, 1972.

9 "Controlling Emissions with the Stirling Engine," *Automotive Engineering*, April 1973.

10 Saliki, J. T., "Electrical Car Facts and Fancy," *IEEE Spectrum*, June 1972.

11 "Another New Engine Nudges Detroit," *Business Week*, Oct. 24, 1970.

12 Thur, G. M., "The Federal Government Approach to Develop Automotive Gas Turbines," *Gas Turbine International*, July-Aug. 1972.

13 "Cumulative Regulatory Effects on the Cost of Automotive Transportation," OST Report, Feb. 1972.

THE CHANGING AUTOMOTIVE ISSUES

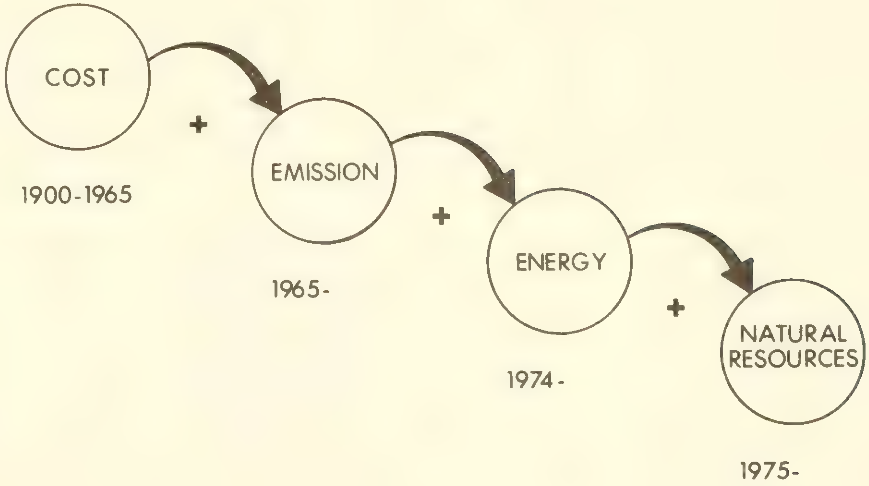


Figure 1

IMPACT ON NATURAL RESOURCES

Several materials which are currently among those in short supply are used in significant quantity in the automobile. Unchecked use will result in depletion before the end of this century. Further, these imports also represent a significant portion of U.S. mineral imports. This could impact directly on the balance of payments.

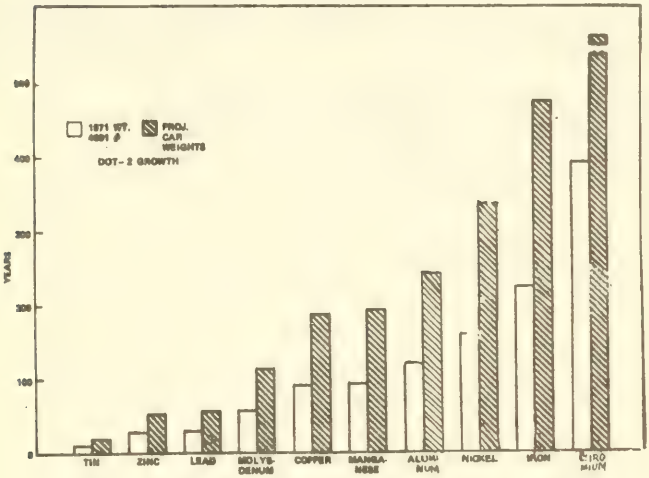

YEARS TO DEPLETION OF U.S. AUTO RESERVE - MATERIALS

Figure 2

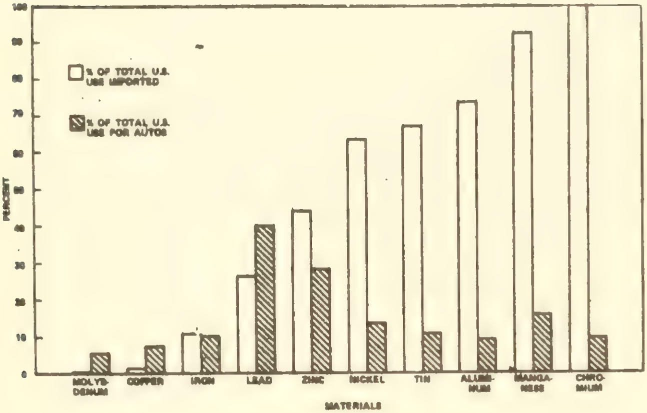

NATURAL RESOURCES - AUTO USE AND IMPORTS (1970)

Figure 3

TABLE I

AUTO METAL CONSUMPTION

(DIRECT AND REPLACEMENT AFTER MARKET)

METAL	DIRECT	AFTER MARKET	TOTAL AUTO USE 1973	TOTAL U.S. USE 1970	PERCENT USED IN U.S. AUTOS
	(POUNDS/AUTO)		(MILLIONS OF POUNDS)		(1950 - 1970 AVG.)
IRON	3,500	496	38,633	324,000	10
ALUMINUM	65	17.7	799.5	7,835	9
LEAD	28	99.3	1,230.7	2,710	40
COPPER	30	7.9	366.4	4,370	7.3
ZINC	65	12.2	746.4	2,300	28.4
NICKEL	4.5	.35	46.9	311	13.7
CHROMIUM	8	.23	79.6	684	9.1
MOLYBDENUM	.5	–	4.8	76	5.6
MANGANESE	12	3.5	149.9	2,296	5.7
TIN	2	.04	19.7	164	10.5

RICHARD D. TAYLOR

99 Muller Road
Kent, Connecticut 06757

June 2, 1975

Representative Mike McCormack Chairman
Subcommittee on Energy Research,
Development and Demonstration.
2321 Rayburn House Office Building
Washington , D.C. 20515.

Dear Sir:

We wish to present the following short statement as testimony before your subcommittee in the current hearing on the Electric Vehicle Research, Development and Demonstration Act of 1975 (HR-5470). The attached material for your records will provide background, qualifications and experimental performance.

* * *

The only practical source of power available for electric vehicles is the lead-acid traction battery which can today provide effective power for short range moderate speed transportation.

Broad public acceptance of electric vehicles however will require batteries of greater capacity with no increase in weight; longer service life; essentially maintenance free operation; and a fool proof system of rapid recharge without damage to the batteries.

The technology is at hand now to accomplish this vital improvement in the power source, and can be readily demonstrated. It consists of:
1.Using calcium-lead alloy in battery plates to eliminate self discharge and corrosion problems prevalent in the present use of antimonial-lead plates.

2. Use of many more and thinner plates to increase the surface area of active material where the power is produced.

3. By supplying the recharge current at the maximum rate at which the battery will accept and store it with no destructive gasing, by using a gas controlled charger which automatically adjusts for variations in temperature and battery condition, provides the fastest possible recharge to the highest percent of original capacity with no damage to the battery and at close to 100% ampere hour efficiency.

* * *

Sincerely,

MAS ENERGY SYSTEMS INC.

R. D. Taylor

cc-Dr.L.A.Currie
Room B-374

UNIVERSITY OF CALIFORNIA, BERKELEY

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DEPARTMENT OF CHEMICAL ENGINEERING
BERKELEY, CALIFORNIA 94720

July 2, 1975

Honorable Mike McCormack, Chairman
Subcommittee on Energy Research, Development,
and Demonstration
Committee on Science and Technology
U.S. House of Representatives
Rayburn House Office Building, Suite 2321
Washington, D.C. 20515

Dear Mr. Chairman:

I hasten to respond to your letter addressed to Dr. J. Ross MacDonald, Chairman of the Motor Vehicle Emissions, NAS-NRC, a copy of which reached me only on July 1. I believe that two publications of the Committee on Motor Vehicle Emissions contain material relevant to H.R. 5470:

1. An Evaluation of Alternative Power Sources for Low Emission Automobiles, Report of the Panel on Alternate Power Sources to the Committee on Motor Vehicle Emissions National Academy of Sciences, April 1963. Section 4: Electrically Driven Vehicles, p. 65-86 of the Report.

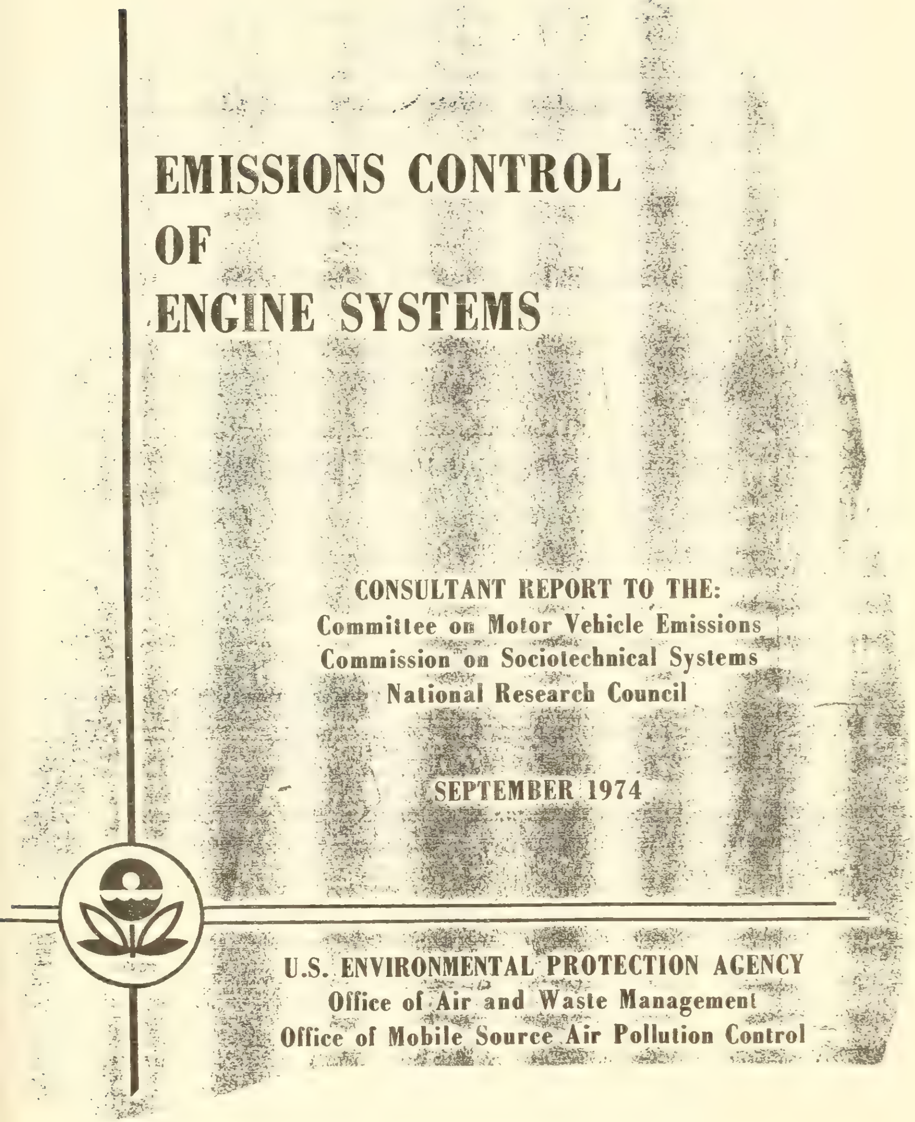
2. Emissions Control of Engine Systems, Consultants Report to the Committee on Motor Vehicle Emissions, Commission on Sociotechnical Systems, National Research Council, September 1974. Section 12.7: Electrically Driven Vehicles, p. 202-212.

I have requested by phone the Commission of Sociotechnical Systems of the National Research Council to send over to you as soon as possible copies of these reports. Xerox copies of the sections mentioned above are enclosed with this letter.

I am, of course, not in the position to judge whether the material described above is suitable for inclusion in the hearing record of H.R. 5470. If in your judgement portions of these reports would serve to strengthen H.R. 5470, I would be pleased if you decided to use them. Funding of a test vehicle program, coupled with a well designed R. & D. effort aimed at the development of substantially improved batteries is, in my opinion, eminently well justified.

Sincerely,
Charles W Tobias
Charles W. Tobias
Professor of Chemical Engineering
Consultant to the CMVE, NAS-NRC

cc: Dr. Earl W. Evans, NRC



EMISSIONS CONTROL
OF
ENGINE SYSTEMS

CONSULTANT REPORT TO THE:
Committee on Motor Vehicle Emissions
Commission on Sociotechnical Systems
National Research Council

SEPTEMBER 1974

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control

CONSULTANT REPORT

to the

Committee on Motor Vehicle Emissions

Commission on Sociotechnical Systems

National Research Council

on

EMISSIONS CONTROL OF ENGINE SYSTEMS

PREPARED BY:

James E. A. John, Chairman, Engine Systems

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Washington, D.C.

September 1974

PREFACE

The National Academy of Sciences, through its Committee on Motor Vehicle Emissions (CMVE), initiated a study of automobile emissions-control technologies at the request of the United States Congress and the Environmental Protection Agency (EPA) in October 1973. To help carry out its work, the CMVE engaged panels of consultants to collect information and to prepare consultant reports on various facets of motor vehicle emissions control. This _Consultant Report on Emissions Control of Engine Systems_ is one of five consultant reports prepared and submitted to the Committee in connection with the _Report by the Committee on Motor Vehicle Emissions_ of November 1974. The other consultant reports are:

> An Evaluation of Catalytic Converters for Control of Automobile Exhaust Pollutants, September 1974
>
> Emissions and Fuel Economy Test Methods and Procedures, September 1974
>
> Field Performance of Emissions-Controlled Automobiles, November 1974
>
> Manufacturability and Costs of Proposed Low-Emissions Automotive Engine Systems, November 1974

These five consultant reports are NOT reports of the National Academy of Sciences or its Committee on Motor Vehicle Emissions. They have been developed for the purpose of providing a partial basis for the report by the Committee as described more fully in the cover NOTICE.

ACKNOWLEDGEMENTS

The authors would like to thank Drs. Robert F. Sawyer and Nicholas P. Cernansky for their contributions to this consultant report.

12.7 Electrically Driven Vehicles

a. Introduction -- The assessment of the performance of present and anticipated electrically driven vehicles as presented in Reference 116 requires additions and corrections in the light of new developments. Recent vehicle systems studies,[180-186] battery and vehicle test programs[186-189] and advancements in battery technology[190-194] allow a more concrete appraisal of future vehicle capabilities. The gasoline fuel shortage experienced during the past year, as well as the rapidly rising cost of crude oil, have provided a powerful spur for seeking alternative power sources for transportation. Electric vehicles, at least on superficial examination, seem to offer potentially significant fuel savings. (183,188,195,196)

It is well understood, of course, that the use of electrical drives in vehicles entirely removes the polluting source from the vehicle and transfers it to the central power plant. The cleaning up of emissions from power plants need not be considered here; this problem is already receiving intensive attention. The additional power demand by electric vehicles seems not serious considering the unavoidable low rate at which such vehicles could be added to the present transportation scheme. For instance, if all driving in the USA were by electric cars (approximately 10^{12} miles per year) requiring about 0.4 kwhr/mi, the nighttime average electrical generating capacity required for charging would be about 150,000 megawatts. This is not much greater than the present nighttime excess generating capacity in the United States. Gradual introduction of electrical vehicles should result in demands less than the excess capacity.

b. Batteries -- Results of recent test programs and of developmental efforts lead to the following assessment of present and future capabilities of batteries:

(1) The lead-acid battery is the only currently available electric sotrage system for automotive traction with a reasonable cycle life and cost per unit energy stored. Its key limitation, energy storage density, can be improved sufficient (from 10 to 12 whr/lb to about 13 to 15 whr/lb) but this is not to permit application beyond marginal-performance urban vehicles, delivery vans and busses.[197] Even if the cycle life were to be extended to 1,000 deep cycles, the amortization of the battery over its lifetime will lead to a cost of the battery alone amounting to 3-5 cents per kwh delivered.[180-182,184]

(2) Other battery systems with "intermediate" performance will very likely become available within the next five years;[187,190] see Table 12.3. Although these promise to provide two-to-threefold improvement in energy density, relative to the lead-acid battery, it is unlikely that their cycle life can be sufficiently improved to provide economically attractive energy storage cost. However, because the future Zn-NiOOH system may have good power capability, its application in electric vehicles and perhaps in gasoline-electric or battery-battery electric hybrids deserves consideration.

(3) Recent advancements in the technology of the solid electrolyte (beta-alumina), as well as in other critical areas affecting the feasibility of alkali metal sulfur systems, increase confidence in the eventual technological feasibility of high-energy, high-power density battery systems.[182,192,195] Prototype producing and testing programs should provide definitive answers in the next three to five years as to whether the alkali-metal-sulfur batteries can provide an economically viable solution to the energy storage needs of electric vehicles. Indications at present (Table 12.3) are that battery amortization costs may achieve a level below 1/cent/mile. Current work on the feasibility of battery schemes employing alkali-metal

TABLE 12.3

Batteries for Electrically Driven Vehicles

System	Theoretical	Best Present Performance					Anticipated Performance					
	whr/kg	wh/kg	peak w/kg	cycle life	operating time, year	cost $/kwh	wh/kg	peak w/kg	cycle life	operating time, year	cost $/kwh	year
$Pb/H_2SO_4/PbO_2$*	175	22 to 26	100 to 200	300 to 1,000	1.5 to 2	30 to 50	28 to 33	100 to 200	500 to 1,000	3	40 to 50	1976/ to 1978
Zn/KOH/NiOOH	326	55	100** to 200	200	1	100	30** to 35	100** to 200	500**	3	30** to (1) 50	1978*/ to 1980
$Zn/ZnCl_2/Cl_2.6H_2O$	465	70	50	10	?	?	110	100	500	3	50	1980
Fe/KOH/NiOOH	267	36	35	2,000	3	50	44	100** to 200	500	5	50 (1)	1978
H_2/KOH/NiOOH	381	65	40	1,000	1	?	80	100	3,000	3	100 (1)	1980
Li/LiCl.KCl/S	2,500	150	150	100	0.2	?	330	200	1,000	3	20 50	
$Li_2Al/LiCl.KCl/FeS_2$	790	120	120	200	0.5	?	200	200	1,000	3	20 50	1980
Na B-Alumina or Na-glass S	760	90	150	1,500	1	?	180	200	1,000	3	20 50	

*Data and estimates pertain to deep (70-80%) discharge at 1-3 hr rate. Range of numbers refer to range of usage.

**Ranges refer to uncertainty.

(1) With metal recovery accounted for.

negative electrodes at lower temperatures (in the range of 200°C) shows good initial promise.[190] Significant advantages in cell construction technology and cost may be derived from operation at this lower temperature level. Production of significant numbers of electric vehicles based on alkali metal batteries cannot be expected before 1985 at best.

c. Electric drive train -- There are a number of viable alternatives for motor and switch-gear systems suitable for use in electric vehicles. Systems studies and experimental test programs indicate that electric systems which have favorable torque and speed-control characteristics combined with high efficiency will have initial costs (excluding the battery) comparable to or higher than the present-day drive train of gasoline-powered automobiles.[182,183,185] Weight of the drive train depends greatly on the system, although the order of magnitude appears to be about 1½ to 2 kg/hp. The VW van being worked on at DAUG and VW suffers a weight penalty of about 100 to 200 lbs for an electric vehicle without batteries compared to a gasoline-engine-powered van. Motor and switch gear possessing optimal characteristics for electrics are not yet fully developed. The drive train aspect of electric vehicles, however, does not appear to present the limiting factor in the eventual realization of efficiency and economically attractive electrical vehicles.

d. Hybrids -- Recent tests by EPA on a gasoline-engine-battery-hybrid vehicle (Petro Electric)[198] demonstrated with a 4,000 lb vehicle the following emissions and fuel economy over the Federal Driving Cycle:

HC	CO	NO_x	MPG (avg)	MPG (engine off at idle)
(grams per mile)				
0.45	2.08	0.90-1.14	10.4	12.4

A Wankel engine and lead-acid batteries were used. The driveability of this vehicle was acceptable. Further improvements in meeting emissions standards and in gas economy can be expected by using a conventional small gasoline engine rather than the Wankel employed in this test vehicle. Other test programs involving hybrids[185,187] have not produced as yet sufficient data on emissions characteristics and on energy efficiency to make meaningful conclusions possible. Because hybrid drive systems are more complex than either of the derivative systems, the initial cost of the vehicle promises to be high. However, the anticipated longer cycle life of advanced battery systems may provide a basis for favorable vehicle cost per mile.

Tests conducted at EPA in October-November of 1974* with the Petro-Electric vehicle yielded the following results:

HC	0.38 g/mi
CO	2.41 g/mi
NO_x	0.76 g/mi
MPG	9 urban
	16 highway

These results were obtained at 4,000 lb inertia weight and with a high rear-end ratio. The mileage is for the battery recharged to its starting level. A rotary engine is used in conjunction with the electric system. Using an EPA determination factor for a rear-end ratio one half that used in the test, and the improved economy of a piston engine versus a rotary engine, the predicted urban mileage would be $1.35 \times 2^{.6} \times$ measured value = 17.9 mpg. Past EPA tests on the Petro-Electric vehicle have indicated highway mileage nearly double the urban mileage.

The electric system includes a set of starter, light, and ignition (SLI) batteries having 90 amp hours of storage. Discharge is only by 2 amp hours before recharging starts and does not normally exceed 6 amp hours during operation. Also included is an electric motor rated at 10 hp continuous, or 20 hp for one minute, or 40 hp for acceleration.

---

* Telephone call from H. Wouk, President, Petro-Electric Motors, Ltd. to J. Bjerklie, December 12, 1974.

Costs have been resolved except for the batteries and the motor in large production. Including these items, the purchase cost of the Petro-Electric vehicle would be between 10%-20% higher than the equivalent gasoline-engine-powered vehicle for the same emissions and performance. (Note: This information was approved and added to the consultant report December 13, 1974.)

(e) Power demand -- Most recent estimates on power demand[181,195,196,199] to be created by electric vehicles tend to confirm earlier estimates according to which the availability of centrally generated electrical power and of distribution network is not likely to present a constraint on the introduction of even a moderately large population (i.e., addition of 1-2 million vehicles/year) of such vehicles. Because of the load leveling potential of electric vehicles (i.e., charging during off-peak periods), economical benefits may be derived from such a power demand resulting in lowering the average cost of power.[196] In the planning of central load leveling facilities, it would be of distinct advantage to be able to rely on competent estimates regarding the expected penetration of electric vehicles in the transportation system.

(f) Energy economy -- The energy requirement of an electrically driven vehicle compared to that of a gasoline-driven car has been estimated by a variety of methods.[180-184,188,195,196,199] Because of the paucity of road-test data on electrics, a fully reliable comparison is still not available. One of the key difficulties in making a valid comparison between even the smallest gasoline-driven automobile and an electric vehicle available for road tests is that at present the only battery system (i.e., the lead acid) at all suitable for vehicular application provides extremely limited power and range. Once we put together on paper an electric car with performance similar to at least the smallest cars on the road today (Honda, Pinto, Vega, VW, etc.), we must anticipate performance of batteries which are not yet available.

Keeping the foregoing remarks in mind, recent system-performance studies provide the following estimates:

The energy requirements per mile of lead-acid-driven electrics using current technology for the frame and driving train are comparable to the subcompacts on the road today[182,184] (0.25 to 0.5 kwhr/mile). This disappointing performance results from the very high weight of the battery required for even a marginal vehicle range and marginal acceleration/hill-climbing capability.

The energy requirements per mile for cars powered by "intermediate"-type batteries (e.g., NiOOH, $Ni\text{-}H_2$) can be expected to be comparable to those of current subcompacts. The higher energy density and power density of these intermediate battery types will considerably reduce vehicle weight.

The energy requirement of electrics using alkali metal-sulfur batteries, with energy and power densities in the range of 100 kwh/lb and 100 wh/lb, respectively, should be somewhat lower than present-day, gasoline-driven vehicles (compacts) with comparable performance.

It is worthwhile to compare the amount of raw fuel required per mile to drive electric and heat-engine-powered vehicles. From the results indicated above, it can be assumed that electric cars competitive to subcompact gasoline cars will require an average of about 0.35 kwhr/mile. On the other hand, a family-size car averaging 15 mi/gal requires about 0.45 kwhr/mile. This would correspond to an intermediate-size car powered by a Stirling engine. The conversion of raw fuel to drive-shaft power would be approximately as follows:

		Electric Car	Heat Engine
Fuel processing efficiency	=	.9	.9
Power plant efficiency	=	.32	.19
Trnasmission line efficiency	=	.91	
Battery charge/discharge efficiency	=	.7	
Motor/control efficiency	=	.8	
Transmission and gear	=	____	.9
Overall efficiency	=	.146	.154

Adjusting for the difference in kwhr/mile required by the two modes of transport, the ratio of electric vehicle to heat engine vehicle fossil fuel requirements is 0.82. This ratio is low enough to induce some interest in electric vehicles at the present time.

If the transportable fuel of the future requires more thermal or electrical processing than indicated above, the energy ratio will drop further since the fuel processing efficiency for electrical generating plants need not change so long as fossil fuels are used. For instance, if hydrogen were to be required for automobile fuel in the future, and if it were to be generated electrolytically, the ratio will be under 0.6. This should include higher interest in electric cars if energy remains a potential major national problem.

g. Summary:

(1) There are no alternative engines that can be available in mass production for automobiles of standard size and performance before the 1980's.

(2) All of the alternative heat engines can be made to meet the 1978 emissions standards, with Stirling engines and steam engines able to do so most easily and with least controversy on interpretation.

(3) Present gas turbines show poor fuel economy in urban driving, but could be made to show good characteristics for touring-type driving.

(4) High-temperature gas turbines with ceramic components for high-temperature portions of the engine should be technically competitive with spark-ignition engines over 50 hp and should demonstrate excellent fuel economy over a Federal Driving Cycle. Their economic competitiveness is not now clear.

(5) Stirling engines should ultimately be technically competitive with spark-ignition engines over the power spectrum used by conventional automobiles. It is a necessary, but not sufficient, condition to achieve a control system and heater head that can be made at a considerably lower cost than at present to be economically competitive.

(6) Steam engines have been shown to be technically suitable as an exhaust-clean engine for powering lightweight cars.

(7) None of the alternative heat engines have been shown to be suitable in the hands of the public, although gas turbines come closet to having done so.

(8) None of the alternative heat engines have been shown conclusively to have a suitable cost structure for use in conventional automobiles.

(9) Light vehicles powered by efficient, externally heated engines (such as Stirling), using heat stored in a thermal storage system, are being studied for their suitability as an urban vehicle. The system has not yet been shown to be economically competitive.

(10) Heat engine-battery hybrids have beem demonstrated successfully at the EPA to achieve on the Federal Driving Cycle; HC = 0.45 g/mi, CO = 2.08 g/mi and NO_x = 0.9 to 1.14 g/mi, and to negotiate the Federal Driving Cycle successfully.

(11) Flywheel systems have not been shown to be competitive with spark-ignition engines costwise, technically, or for overall emissions.

(12) Based on present technology, it is feasible to manufacture electrically driven personal vehicles for restriced (low range and power) urban use. These vehicles, even when equipped with the best, currently available, lead-acid storage batteries, will have significantly higher initial cost and vehicle cost per mile than today's gasoline-driven subcompacts with no improvement in overall energy efficiency.

(13) Active development programs exist for battery-powered delivery vans and urbans busses. Their duty cycle offers an opportunity that is thought may prove economically viable for the introduction of electric drives and lead-acid batteries.

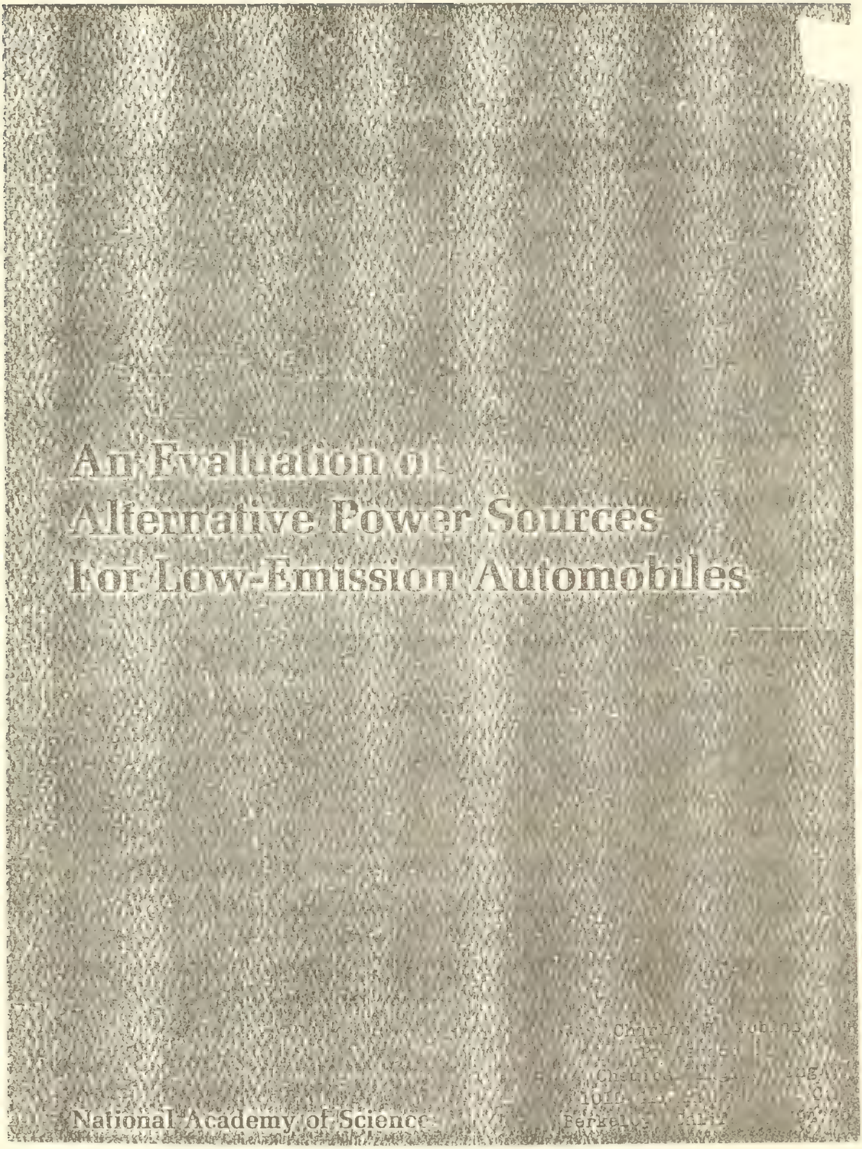
(14) By substantially increasing the cycle life of lead-acid batteries, major improvements in energy economy and vehicle cost per mile may be achieved by decreasing the cost per mile of the battery. Significant improvement in range is not likely to be achieved with the lead-acid battery.

(15) Other battery types currently in advanced development stage (e.g., Zn-NiOOH, H_2-NiOOH) may be expected within five years to provide approximately twice as high specific energy (range) and significantly improved power capability compared to the current best lead-acid system.

(16) The high energy and power density alkali metal-sulfur batteries currently under development show good promise and should reach advanced testing stage in two to three years.

(17) In view of the strong likelihood for a gradual shift toward coal-nuclear-geothermal and, perhaps, solar primary energy sources, there are incentives for the development of advanced storage batteries for electrically driven vehicles.

(18) A summary of fuel economy data for alternative engines is given in Figure 12.3.



An Evaluation of Alternative Power Sources For Low-Emission Automobiles

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PREFACE

In legislating the Clean Air Amendments of 1970, the Congress asked the Environmental Protection Agency to contract with the National Academy of Sciences to conduct a comprehensive study and investigation of the technological feasibility of meeting the motor vehicle emissions standards prescribed in accordance with the law. In responding to this request, pursuant to a contract with the Environmental Protection Agency, the Academy established a Committee on Motor Vehicle Emissions and charged it with the conduct of this study. The Committee published the results of its work in a report to the Environmental Protection Agency dated February 12, 1973.

As means of providing itself with authoritative information and expertise in the various critical aspects of the problem it undertook to study, the Committee appointed specialist panels to undertake investigations and report their findings. The following report, An Evaluation of Alternative Power Sources for Low-Emission Automobiles, presents the findings of one of those panels.

Taken together, the special panel reports constitute a very substantial accumulation of data and analysis brought together by many specialists in many investigations in a very fast-moving area of technological development. In its published report, the Committee on Motor Vehicle Emissions has, of course, brought together that part of all this information and analysis required to fulfill its stated obligation to the Environmental Protection Agency. The separate reports of the specialist panels are published for the public record and to complete the documentary record.

Members of the Panel on Alternate Power Sources were:

John Bjerklie
Schnectady, New York
Panel Chairman

Elton J. Cairns
Senior Scientist
Chemical Engineering Division
Argonne National Laboratory

Henry J. Korp
Howell Corporation

Charles Tobias
Department of Chemical Engineering
University of California

David G. Wilson
Department of Mechanical Engineering
Massachusetts Institute of Technology

Clarence Zener
University Professor
Carnegie-Mellon University

Kurt H. Weil
Special Consultant to the Panel

4. ELECTRICALLY DRIVEN VEHICLES

SUMMARY

Electrically driven vehicles, in principle, provide freedom from pollution and have high energy efficiency, flexibility of performance, durability, and low maintenance costs. The limiting factor relating to the technical and economic feasibility of electric vehicles is the vehicular power source. Electric drive systems having excellent characteristics have been demonstrated; development of optimal electric drive systems is not considered to be limiting in the ultimate realization of electric automobiles.

Fuel-cell powered electric vehicles in which the free energy of fossil fuels is directly converted into electrical energy for motive power do not emit CO or NO_x; unused hydrocarbons can be easily removed from the exhaust. Fuel cell systems which contain a reformer (which produces a hydrogen-rich fuel stream) are also capable of very low HC, CO, and NO_x emission.

Fuel cells are not heat engines and are not subject to the Carnot efficiency limitation. For this reason they may operate at high energy conversion efficiency, resulting in superior fuel economy. Fuel consumption rates one half those of present-day automobiles may be expected.

Although some fuel-cell systems have been successfully deployed in space missions, these are not adaptable for applications requiring low cost. Current advanced developments directed toward stationary applications in commercial and consumer markets are in the field-test stage. These represent important cost reductions and performance improvements relative to the aerospace units. With further significant cost and performance improvements, vehicular applications in small quantities may become feasible within 10 to 15 years.

Vehicles employing rechargeable batteries as power sources do not have emissions resulting from the combustion of fuels by the vehicles. The site of emissions is transferred to central power stations where such emissions are understood to be more effectively controlled and at a lower cost. Because of the high efficiency of batteries and of electric drives, the net fuel economy of such vehicles promises to be better than that of present-day automobiles. Furthermore, if we move toward an electric economy, batteries may assume a unique role in the transportation system.

In contrast to fuel cells, there has been extensive experience in the performance characteristics of at least one battery system: lead-acid. This battery is rugged, efficient, reliable, and can respond instantaneously to large changes in load. Presently available special-purpose vehicles powered by lead-acid batteries can provide ranges of up to 50 miles and modest acceleration, marginally acceptable under urban driving conditions, at a high cost. Other currently available rechargeable batteries such as zinc/silver-oxide and cadmium/nickel-oxide, while superior in selected respects to the lead-acid system, are inherently unsuitable for vehicular applications because of cost and/or materials availability limitations. Still other battery systems currently in various stages of development offer significant performance improvements, and may meet the cost and materials availability criteria necessary for vehicular applications. The zinc/nickel-oxide battery is expected to allow a vehicle design with acceptable acceleration and a range of about 80 miles between recharges.

The most promising of the advanced battery systems are sodium/sulfur and lithium/sulfur batteries, which operate at temperatures in the range 300-400°C and are maintained at operating temperature by their reject heat and appropriate thermal insulation. These batteries are expected to have specific energies of 100 w-hr/lb and specific powers of 100-200 w/lb, permitting the design and construction of electric vehicles with excellent acceleration capabilities and a range of about 200 miles between recharges. Single prototype vehicles are now in various stages of preparation. About seven to eight years of optimum effort will probably be required for the development of pilot quantities of these batteries for more extensive vehicle test purposes. Still other promising battery systems are in early stages of exploration.

Hybrid electric-heat engine power plants are claimed to enable reduction of the emission of air pollutants. The expected improvement in driveability by using the electrical part of the system for power surges should allow the heat engine to operate cleanly and economically at one setting or with a slowly varying setting over a range. There are significant penalties in the areas of cost and complexity that must be overcome before the hybrid can be considered to be a viable contender. Even if the technical and economic criteria can be met, it is doubtful if introduction of this new and relatively complex power-plant scheme will represent any more than an interim solution in respect to pollution abatement and effective use of natural resources.

INTRODUCTION

The incentive for using electrically powered vehicles is based on three fundamental considerations:

1. The vehicle itself is either nonpolluting (in the case of a battery power source) or (in the case of a fuel-cell power source) the levels of noxious gases (HC, CO, NO_x) are well below the 1976 limits set by the Clean Air Act.

2. Because of the inherent high efficiency of batteries, not only is the site of pollution transferred from the vehicle to the central power plant, but the total use of fossil fuels, and therefore the total pollution, is significantly reduced relative to that using the IC engine. The use of fuel cells for vehicle propulsion also reduces the demand for fossil fuels.

3. Since battery driven vehicles can be expected to be charged largely during time periods when off-peak power is readily available,

a higher utilization of power-plant investments (a higher load factor) and therefore reduced energy costs for the overall system would result if electric cars were to be introduced in significant numbers. As nuclear power generation assumes an increasing importance in the total energy generation spectrum, the use of off-peak capacity for recharging the batteries of electric vehicles would offer an even more significant advantage in respect to efficient use of plant investment, as well as a reduction of operating costs.

Electric automobiles of marginal performance were made in the tens of thousands around the turn of the century. At present their use is restricted to special vehicles numbering in the hundreds of thousands (golf carts, fork lift trucks, and urban delivery vans and light trucks). Electric vehicles available today do not have the range and acceleration capability even approaching the smallest gasoline driven car (1).

The central problem as it has been evident all along, is the lack of availability of batteries with sufficiently high specific energy (w-hr/lb) and specific power (w/lb) capability. Several currently available battery types are characterized by high energy-conversion efficiency and reliability, although at moderately high to very high cost, for application as a motive power source. The improvements needed are in the range of a 5- to 10-fold increase in specific energy, while retaining (and even improving by 50-100 percent) the specific power capability. In addition, before broad applications in the personal vehicle area become possible, the cost per unit of energy storage capability ($/kw-hr) has to be lowered by a factor of 2 to 3 compared with the least expensive system available today--the lead-acid battery. As already demonstrated in various experimental vehicle programs, the development of the electric drive (motor and control gear) that would provide desired vehicle performance and driveability does not appear to be a limiting factor in the technological and economic feasibility of the electric automobile (2, 3). On the basis of what we know today and given sufficient time for further development, there are no reasons why the motor and control gear could not be mass produced at moderate costs, perhaps somewhat below that of the present engine, transmission, and associated gear. Although the complete cost of the power plant, including batteries (or fuel cells) promises to be above that of the present power train and gasoline tank, this difference ultimately may not be very significant compared with a cleaned up (or clean) fossil-fuel driven internal or external combustion engine. The increased initial cost should in part be offset by lower energy and maintenance costs.

Much concern has been expressed about the demand electrically driven vehicles would place on the present or currently-anticipated central power generation capacity and on the power distribution network. Considering the installed power generation capacity in the United States at the end of 1971, 367 x 10^6 kw, and the average power actually used, 200 x 10^6 kw, the difference between the two would have sufficed to provide the total energy actually used by every vehicle driven today in the country (4, 5).

However impressive the above comparison may be, it is by no means suggested that such a high proportion of the total electric energy generated would ever be required for electric cars. Penetration of electric vehicles into the U.S. transportation scheme can occur only very gradually, for reasons which are completely divorced from the availability of power. Even in the late 1980's only a small fraction of all vehicles is likely to be powered electrically. This level of penetration will represent an insignificant percentage demand on the total generating capacity as it already exists, not even considering the planned expansion by 1980-1990. Considering the estimated energy demand (without electric cars) of 10^{13} kwh for the year 2000 (2), an all-electric family car population of 180 million, driven 43.4 km every day, would add less than 15 percent to the anticipated demand (1).

Insofar as the possible need for a greatly expanded distribution network is concerned, it should be noted that for a completely discharged battery of a family car driven 200 miles, a household circuit would only have to provide on the order of 10 kw for 12 hours. This type of load can at present be handled by many households in off-peak periods. Future household circuits will be able to handle, for reasons other than the electric car, the usually much lower average demands for battery charging.

The average cost of electricity, even taking into account the cost of any possible expansion of the distribution network, should be favorably affected by power demands created by electric cars.

ALL-ELECTRIC VEHICLES

Battery-Powered Vehicles

In principle, battery-powered electric vehicles provide an attractive alternative to conventional vehicles powered by spark-ignition engines. Batteries can be pollution-free and provide efficient, silent, responsive power. The use of electrically rechargeable batteries shifts the source of pollution away from the densely-populated areas to the power-generating stations, where emissions can be effectively and economically controlled.

In the past, many battery-powered vehicles have been used and are still in use, but their acceleration and range (miles between recharges) are far lower than those of similar spark-ignition engine vehicles. The problem has been that batteries having sufficient energy storage capability (expressed as specific energy, w-hr/lb), power delivery capability (expressed as specific power, w/lb), and lifetime have not been available at any cost. Experience with special-purpose and demonstration battery-powered vehicles has shown that efficient, flexible, and powerful electric motor and controller systems can be constructed and operated in electric automobiles using presently available technology (2,3,6,7). The costs of the electric drive systems (minus battery) appear to be capable of being reduced to acceptable levels.

A battery-powered automobile capable of performing according to existing urban and suburban driving profiles, with a range of at least

200 miles under these conditions and a battery weight 25 percent of the total automobile weight, requires a battery with a specific energy of 100 w-hr/lb and specific power of at least 70 w/lb (8). Batteries of lower specific energy provide shorter ranges, and those with lower specific power provide lower acceleration capability.

Figure 4-1 shows a plot of the specific power versus specific energy capabilities of various batteries (9). The curves for batteries that are now commercially available (see Table 4-1) show that these batteries are not capable of providing the specific power and specific energy required for a high-performance with a range of 200 miles. But vehicles of more modest performance, such as urban delivery vans and urban buses, can be contemplated, although at an increased investment cost (see Table 4-1, and compare to a goal of about $10/kw-hr to be competitive with spark-ignition engine vehicles).

The lead-acid (Pb/PbO_2) battery represents a well-developed technology and is unlikely to undergo significant, rapid improvements in cost or performance. Vehicles (both passenger and commercial) of marginal performance for urban use (50 miles range, 50 MPH[*]) are now available in limited quantities from at least ten manufacturers. There are now tens of thousands of industrial vehicles of this type and about 200,000 lead-acid battery-driven golf carts in the United States (1). A large variety of electric industrial and consumer vehicles are available in England and Japan (1). In the United States, orders are being placed this year for hundreds of lead-acid battery-driven passenger vehicles (1).

In terms of acceleration and cycle life the Cd/Ni_2O_3 battery offers increased performance (see Table 4-1) but at a very high price, making this approach impractical. Battery manufacturers do not forsee a Cd/Ni_2O_3 battery cost of less than about $400/kw-hr, even in very large quantities, using presently available technology. Furthermore, cadmium is a relatively high-cost ($3/lb) material of low production rate and low reserves.

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[*] All vehicle performance figures quoted in this discussion relate to vehicles having 25 percent of their weight allotted to batteries. Somewhat higher ranges and speeds are possible with a higher battery weight.

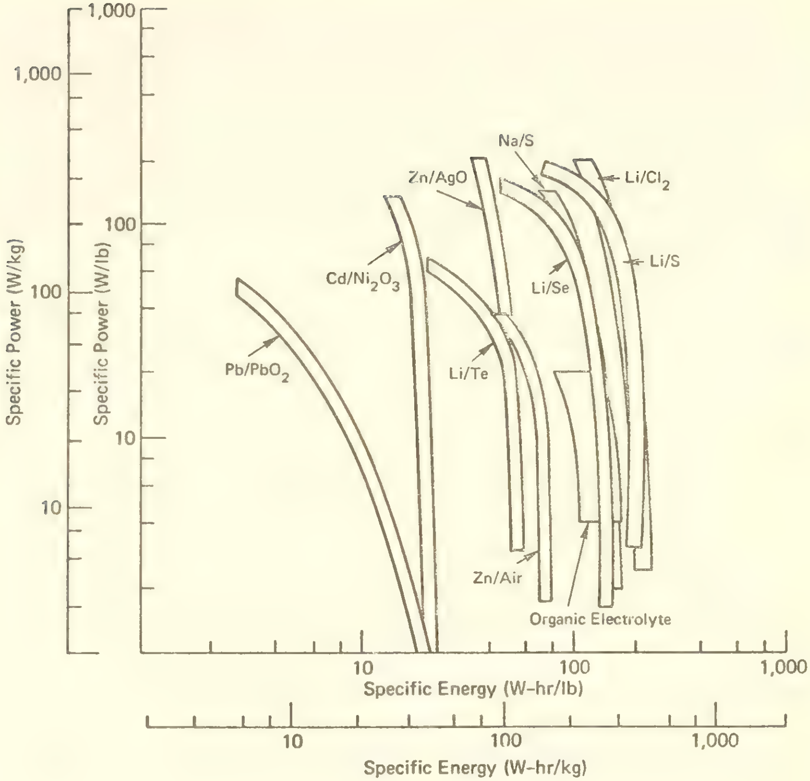

FIGURE 4-1 Specific power vs specific energy capabilities of various batteries.

TABLE 4-1

Characteristics of Batteries[a] and Electric Vehicles

Battery	Electrolyte	Operating Temp. °C	Specific Energy w-hr/lb[a]	Peak Specific Power w/lb[b]	Range,[c] Miles	Acceleration	Cycle Life	Cost[f] \$/kw-hr	Status	Time Dev. Year
Pb/PbO_2	$H_2SO_4(aq)$	Ambient	10-20	75	20-40	Fair	300	20-50	Available	--
Cd/Ni_2O_3	KOH(aq)	Ambient	10-20	150	20-40	Excellent	1000	>150	Available	--
Zn/Ni_2O_3	KOH (aq)	Ambient	25-35	100	40-80	Good	(300)	>100	Laboratory cells and batteries	4
Zn/Ag_2O	KOH(aq)	Ambient	40-55	100	80-100	Good	100	>400[e]	Available	--
Li(Al)/ $TeCl_4$ (C)	LiCl-KCl	360-500	(50-60)	(120-150)	90-110	Excellent	(1500)		~1 kwh prototype batteries	5
Na/S	$Na_2O.xAl_2O_3$ or glass	300-350	(80-100)	75-100	150-200	Good	(1000)	(10-30)	~1 kwh lab batteries	7
Li/S	LiCl-KCl	375-400	(100-120)	(100-200)	(200-240)	Excellent	(1000)	(10-30)	Small lab batteries, sealed cells	8

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[a] Figures in parentheses are estimates for the future, based on present laboratory data.

[b] Urban-suburban driving profile average power level.

[c] Urban-suburban driving requires peak power, at least 70 w/lb, with 100 w/lb preferred.

[d] Urban-suburban driving profiles.

[e] Deep discharge.

[f] Authors' estimate; includes allowance for salvage value.

[g] \$/kw-hr of energy storage capability (one cycle).

The Zn/Ni_2O_3 battery offers a significantly higher specific energy than is available from Pb/PbO_2 or Cd/Ni_2O_3 batteries (25-35 w-hr/lb versus 10-20 w-hr/lb); however, this system is still in the preprototype stage and only hand-made laboratory cells and batteries are available now. A battery of this type, when developed, could probably provide acceptable performance for urban (and perhaps suburban) vehicles, having a range of 40-80 miles, depending on the driving profile. It is estimated that 4 to 5 years would be required (at an optimum funding level) before small numbers of Zn/Ni_2O_3 batteries could be made available for testing in electric vehicles. Present estimates indicate that the future selling price for Zn/Ni_2O_3 batteries in large-scale production may be as low as $100/kw-hr. Processing costs are the main problem, because materials costs are not very high, nor are the materials in short supply.

The Zn/Ag_2O battery offers specific energy and specific power capabilities higher than those available from other aqueous-electrolyte rechargeable batteries. The feature prohibiting its use as a power source for electric automobiles is that it requires a large inventory of silver, which is expensive and in short supply. Furthermore, a significant improvement in the cycle life would be necessary before its use could be seriously contemplated. As an engineering exercise, a high-performance electric automobile containing Zn/Ag_2O batteries was constructed and tested (3). This vehicle demonstrated conclusively that electric vehicles matching performance (but not the range) of their gasoline engine counterparts can indeed be built using presently available technology. The cost, however, is higher, even discounting the cost of the battery.

A review of the state of battery science and technology (9) reveals that only medium-temperature (300-400°C) electrochemical cells have demonstrated in laboratory experiments significant promise of meeting both the specific energy goal necessary for a range (in urban-suburban driving) of 200 miles or more between recharges (100 w-hr/lb) and the specific power necessary for very rapid acceleration and high-speed passing maneuvers consistent with freeway driving (100-200 w/lb).

These cells, which operate at 300-500°C (the temperature to be maintained by thermal insulation and waste heat from the battery generated during operation), make use of nonaqueous electrolytes (ionically-conductive ceramics, glasses, or molten salts) and (usually) liquid electrodes. The negative electrodes are sodium or lithium; the positive electrodes are sulfur or chalcogen (the chalcogens are the members of Group VI B of the periodic chart, and include sulfur, selenium, and tellurium) containing mixtures or compounds. Data for the three most advanced types of medium-temperature batteries are shown in Table 4-1.

The Li(Al)/$TeCl_4$(C) cell (10) makes use of tellurium, which is relatively expensive and probably in short supply, thereby limiting its applicability. However, this cell has reached the most advanced state of development of all medium-temperature cells. Sealed cells have been developed and produced in small pilot quantities for laboratory testing, and some 12-cell batteries have been constructed and tested. These 1/4 kw-hr batteries have demonstrated cycle lives of 100 cycles (individual cells of this type have been cycled more than 200 times). It is believed that this work will continue, with the construction of somewhat larger batteries for testing by the U.S. Army at Fort Belvoir. Approximately five years would be required, at an optimum level of effort, for the development of prototype batteries for electric automobile propulsion. The range to be anticipated is about 100 miles, if 50-60 w-hr/lb can be achieved. The cost can be anticipated to be relatively high, and the tellurium supply will probably be limiting.

From a materials point of view, the sodium/sulfur (11) and lithium/sulfur (8) cells are more promising for widespread use in high-performance electric automobiles. The sodium/sulfur cell contains either a ceramic (beta alumina, $Na_2O \cdot xAl_2O_3$) or a glass (sodium-ion conducting) electrolyte which separates liquid sodium from liquid sulfur. The construction of these cells can be relatively simple, allowing mass production at a reasonable cost (estimated to be $10-30/kw-hr). For a range of 200 miles, a cycle life of 1000 cycles ought to be more than adequate (200,000 miles over the lifetime of the battery). Cycle lives of more than 100 cycles have been demonstrated by single laboratory cells. Sodium/sulfur batteries having a power level of up to 400 watts have already been constructed and tested; a 30 kw battery is already under construction for use in a demonstration vehicle (12). It is estimated that about seven years of optimum effort may be required for the development of pilot quantities of sodium/sulfur batteries for electric automobiles. These vehicles can be expected to have a range of 150-200 miles, with good acceleration capabilities.

The lithium/sulfur cell using a molten LiCl-KCl electrolyte (8,9), which shows promise of even higher specific energy (100-120 w-hr/lb) and specific power (100-200 w/lb), is in the small lab cell and small battery stage of development. Unsealed cells have delivered 1000-2000 cycles (operating continuously for 6 mos- 1 yr); sealed cells have delivered 100-200 cycles during about 1000 hours of operation; a sealed 3-cell battery has delivered 6 cycles during 200 hours of operation. It is projected that about 8 years of development at the optimum rate will be required to reach the pilot test stage in electric automobiles. The ultimate cost may be in the range of $10-30/kw-hr. The performance of an electric vehicle with Li/S batteries as the power source should essentially match that of present gasoline-engine vehicles. The range is expected to be 200 miles or more. The cost of the vehicle is expected to be somewhat higher than the present-day vehicle.

In order to provide some design-related information for electric automobiles, some estimates have been made for the weights of the various major components of three classes of electric vehicles: future full-size electric family auto; future compact electric auto; and urban subcompact auto of marginal performance, available now. Table 4-2 shows the weight distribution by components. The family and compact autos are assumed to be powered by lithium/sulfur batteries having the same performance per unit electrode area as typical laboratory cells of 1971; the urban auto is assumed to be powered by lead-acid batteries available now. The weights of the components have been estimated by the authors and are intended to be representative of currently available electric vehicles (1).

TABLE 4-2

Some Specifications for Three Electric Automobiles

Type	Family	Compact	Urban
Curb weight	4300 lb	1800 lb	1650 lb
Test weight	4600 lb	2200 lb	1850 lb
Weight of power plant:			
Battery	1075 lb[a]	600 lb	$\sim$900 lb[b]
Motor	150 lb	100 lb	$\sim$100 lb
Controls	200 lb	110 lb	$\sim$30 lb
Transmission and drive train	70 lb	50 lb	50 lb
Air conditioner and heater	80 lb	20 lb	-
Miscellaneous	25 lb	20 lb	$\sim$20 lb
Total[c]	1600 lb	900 lb	1100 lb
Accessory power:			
Lights, radio, etc	250W	250W	$\sim$150W
Air conditioner	3000W	-	-
Air Draft Coefficient	0.5	0.5	$\sim$0.5
Frontal area of vehicle	24 ft^2	20 ft^2	$\sim$20 ft^2
Transmission efficiency	0.82	0.82	$\sim$0.75

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[a] Lithium/sulfur battery assumed for performance calculations.

[b] Lead-acid battery assumed for performance calculations; authors estimates of typical weights for available vehicles.

[c] Include in curb weight and test weight.

Computer calculations of the ranges of the family and compact autos were performed, using published driving profiles, specific battery designs, and laboratory cell performance data as inputs (8,13,14). The results, shown in Table 4-3, indicate that electric automobiles powered by batteries having a specific energy near 100 w-hr/lb and a specific power near 100 w/lb can be expected to meet present-day urban-suburban driving patterns, and have a range of 125-250 miles between recharges. Presently available lead-acid battery-powered urban vehicles can provide a range of about 50 miles between recharges, with marginal acceleration, at a cost premium.

Fuel Cells

Direct conversion of the free energy of combustion of fuels to electrical energy has been shown to be technologically feasible; operating hardware has served as the auxiliary power source of the Gemini and Apollo space vehicles. A general review of thermodynamic and kinetic principles and of engineering and technological aspects has been given, among others, by Liebhafsky and Cairns (15). The state of the art to 1967 has been reviewed by the Panel of Electrically Powered Vehicles of the U.S. Department of Commerce (16).

Using hydrogen (or an alcohol), a fuel cell system emits only water vapor and CO_2. When the primary fuel is a hydrocarbon, which has to be reformed into hydrogen and carbon dioxide, emissions of NO_x also occur, at levels, however, well below the limits specified for 1976. Emission of NO_x results from the burning of fuel to heat the reformer. A special class of fuel cells operating at high temperatures ($\sim$ 1,000°C) can accept H_2 or mixtures of H_2 and CO as a fuel; these are not expected to emit NO_x, only water and CO_2. Thus from the point of view of pollution abatement, fuel cells based on either hydrogen or hydrocarbons can perform entirely satisfactorily.

Fuel cells may be described as continuous feed primary batteries; the reactants are continuously fed to the reaction sites (the fuel to the anode, air or oxygen to the cathode). The reaction conditions in the cell itself are time invariant. Efficiency remains high over a

Table 4-3

Ranges fos Electric Vehicles under Various Driving Conditions

Vehicle	Family	Compact	Urban
Accessory Power, watts	250	250	0
Regenerative Braking Efficiency	0	0.5	0
Urban driving range, average miles	200	250	~50
Suburban driving range, average miles	150	125	--

very broad range (25-125 percent) of the nominal load rating for a well-designed fuel cell power plant. Fuel-cell systems carry the fuel in separate tanks, similar to heat engines, instead of in the reaction vessel itself, as batteries do. In principle, therefore, fuel cells should be capable of providing a similar range to the present-day automobile. The energy conversion efficiency of fuel cells, in principle, is significantly higher than any mobile or stationary power plant presently in use. Since the conversion process is not subject to the Carnot limitation, the heat rejected to the surroundings amounts to the sum of $T\Delta S$ of the net reaction and of the irreversible losses due to conduction in the electrolyte and those losses associated with such processes as the charge transfer reactions at the electrode surfaces, and mass transfer. Efficiencies of 40 to 60 percent (based on the heat of combustion) at moderate power drain have been convincingly demonstrated in prototype hardware (17,18). High energy-conversion efficiency gives a powerful incentive for serious consideration of application of fuel cells as power sources in automobiles.

In its present stage of development, certain fuel cell hardware was proven to be very reliable over long periods of continuous or interrupted use, capable of handling large overloads for short periods of time. The operating period required for economic feasibility is approximately 16,000 hours. A complete power conversion system (19,20) is currently undergoing field testing for stationary energy conversion from natural gas to electricity. The inherent problems in the development of fuel cells for general consumer use are associated with capital cost per unit power capability and lifetime.

Significant effort has been devoted to the development of fuel cells--including some directed to automotive applications--in the past twenty years. Of the numerous private enterprises that have had major programs in this area, today only one (Pratt and Whitney Aircraft Division of United Aircraft) has a massive commitment in fuel-cell development and in limited manufacture (19,20). The continued engineering developmental effort of P&W has resulted in noteworthy advances in the state of the art and suggests a revision of prognostication for potential application of fuel cells as power sources in personal vehicles (16,20).

Major advances as related to phosphoric acid electrolyte cells can be summarized as follows:

1. Significant reduction of platinum catalyst loadings of electrodes from 12 g/ft^2 (1965) to below 2 g/ft^2 (1972), without loss of performance (21).

2. Development of sophisticated manufacturing technology for the mass production of cell stacks involving modules of thin cells. Extensive use of low-cost electronically conducting materials (carbon) and insulators (polymers) is bringing the cost of cell hardware to within the realm of economic feasibility for consumer use.

3. Development of simple, small, and inexpensive catalytic reformers, which convert the hydrocarbon fuel into hydrogen, CO_2, and water vapor. The power plant emits H_2O, CO_2 and low levels of NO_x.

Based on known technology, complete units in the range greater than 10 kw may become feasible at a cost of $100/kw (includes reformer and DC-AC converter). Further reduction of cost may be possible if and when noble-metal catalyst loadings can be still further lowered, or eventually completely replaced. Developmental efforts continue with an objective of further reducing costs on (a) other cell types involving acid electrolytes; (b) KOH electrolyte; and (c) high temperature, molten electrolytes. The use of other hydrogen-containing fuels (e.g., ammonia, hyrazine, alcohols) is also promising.

In respect to application in personal vehicles, no meaningful predictions can be made at this time. A few vehicles powered by fuel cells have been constructed and road tested (22,23) to define development goals on the basic electric drive components (the motor, electric drive, and power source). The overall thermal efficiency has already been proven to be at least twice as high as that of the gasoline engine in average use. Heavy weight, large volume, and high initial cost (these did not involve presently available fuel cell technology) appeared to be the problems directly related to fuel cells.

Estimates based on currently available technology indicate that power levels in the range of 50 w/lb may be accessible, at $100/kw (power system cost). This power capability is not sufficient to match the performance of the present family car, and the cost per kilowatt is five to ten times higher than would be necessary to match the equivalent gasoline-engine-powered vehicle. Nevertheless, the advancements made in fuel-cell technology indicate that they should no longer be dismissed from consideration as a potentially economically feasible alternative power source. However, it is unlikely that fuel cells with appropriate power and cost characteristics can be developed and ready for broad application in the personal vehicle sector in less than 15 years.

Fuel cells are in a stage of development that does not permit firm predictions to be made about their potential availability for application in personal vehicles. If noble metal catalyst loadings can be further reduced (or entirely eliminated) and if manufacturing technology for the cell stacks can be advanced to the point where cost is lowered to the range of $30-50 per kw, the incentive for the deployment of fuel cells as a power source in vehicles becomes strong. Depending on primary fuel, they are pollution free, or nearly so, efficient, and potentially very durable. The electric power source affords broad possibilities for the design of prime movers yielding favorable vehicle performance characteristics and good driveability.

A further incentive for seeking the advancement of fuel cell technology with applications in vehicles as a definite goal may be derived from the energy source-distribution picture, as it is estimated to evolve over the next 15-30 years. It is generally agreed that up into the first decades of the twenty-first century, fossil fuels will provide a major fraction of the primary energy. Use of fuel cells in transportation would improve the efficiency of use of these resources. On the other hand, considering the shift toward an all-electric economy, the distribution of electrical energy from central stations may involve central generation of a suitable fuel (H_2, NH_3, etc.) and its distribution in a network of pipelines. The end use could then include reconversion by fuel cells into electric motive power in vehicles. The high inherent thermal efficiency of fuel cells therefore could be of interest even when fossil fuels cease to be a major factor in the energy economy.

HYBRID ELECTRIC VEHICLES

A number of schemes have been proposed for the operation of hybrid electric vehicles in which a heat engine is combined with a battery, an electric drive, and a control system (24,25,26). The intention is to minimize the emission of pollutants by operating a suitably-tuned heat engine (SI, diesel, gas turbine, etc.) at a fixed operating point while providing the varying component of the propulsion power from a battery-powered electric motor. It is possible to use the electric motor mechanically in parallel with the heat-engine drive (24), or in series with it. The use of the electric motor adds significantly to the driveability of the vehicle when the SI engine is tuned for minimum emissions (yielding low power and poor driveability).

It may be necessary to allow the heat engine to follow the demand, probably with a slowed response in order to have a vehicle capable of a wide range of power levels. Because of the fact that the battery will usually be operated at high current densities, the overall energy efficiency will be low (perhaps below 50 percent), resulting in higher fuel consumption than would otherwise be the case. While this scheme has been shown to be technically feasible, the 1976 emission standards have not been met for a significant period, and presently-available batteries have been shown to have an inadequate lifetime. The combination of increased fuel consumption, increased complexity and cost, and the need for improvements in emission control equipment and batteries makes the attractiveness of heat engine-electric hybrid vehicle at best a marginal solution to the pollution problem.

It is possible that the 1976 emissions standards could be met by heat engine-electric hybrid vehicles, but it appears that this solution to the problem is likely to be of an interim nature, since future improvements in either heat engines or batteries (including fuel cells) could displace the more complicated and less efficient hybrid system. Recognizing the likely interim nature of this approach to minimizing motor vehicle emissions, it is difficult to imagine that industry would undertake the development and large-scale production of heat engine-electric hybrid vehicles.

To put it succinctly, a good hybrid power plant would need a fairly clean engine and a better battery than what we have today. The combination of these two could yield a vehicle emission performance acceptable under the 1976 standards. However, if these were available they could be solutions in themselves. Therefore, if one considers the developmental and manufacturing costs, and the strong likelihood that hybrid vehicles would have only an interim significance in the transportation spectrum, it appears unlikely that they will play a significant role in the solution to the automotive emission problem.

POTENTIAL AVAILABILITY

Battery-operated vehicles exist now, and limited-production battery-powered automobiles could be said to exist, albeit with low performance and small size. Mass production of these limited performance vehicles could be achieved in four to six years if required.

Advanced battery power plants are estimated to be about four years from a suitable prototype assuming optimum funding. If this schedule could be held, mass-produced electric-powered vehicles of high performance could conceivably become available in an additional seven to ten years.

Advanced fuel cells are estimated to be at least 15 years away from a suitable prototype, even with suitable funding.

REFERENCES

Discussions

General Motors Corporation

Ford Motor Company

Chrysler Corporation

Petro-Electric Motors, Ltd.

U.S. Army Mobility Equipment Research & Development Center

General Electric Company

Pratt & Whitney, Division of United Aircraft Corp.

Papers

1. Proceedings of the Second International Electric Vehicle Symposium, Electric Vehicle Council, New York, 1972.

2. Agerwal, P. D., and Levy, I. M., SAE paper 670178.

3. Rishavy, E. A., Bond, W. D., and Zechin, T. A., SAE paper 670175.

4. Salihi, J., IEEE Spectrum, June 1972, p. 44.

5. Kyle, M. L., Cairns, E. J., and Webster, D. S., Lithium/sulfur batteries for off-peak energy storage--A comparison of energy storage and peak power generation system, Argonne National Laboratory Report (in press).

6. Foote, L. R., and Hough, J. F., SAE paper 700024.

7. Martland, L, Lyne, A. E., and Foote, L. R., SAE paper 680428.

8. Kyle, M. L., Shimotake, H., Steusenberg, R. H., Martino, F. J., Rubishko, R., and Cairns, E. J., 1971 IECEC, p. 80.

9. Cairns, E. J., Steunenberg, R. K., and Shimotake, H., in Kirk-Othmer Encyclopedia of Chemical Technology Supplement, 1971.

10. Metcalfe, J. E., Chaney, E. J., and Rightmire, R. A., 1971 IECEC, p. 685.

11. Kummer, J. F., and Weber, N., SAE paper 670179.

12. Jones, I. W., Electricity Research Council Laboratory, Capenhurst, England, private communication to E. J. Cairns, May 1972.

13. Cairns, E. J., et al., Development of high-energy batteries for electric vehicles, Argonne National Laboratory Report no. ANL-7888, Dec. 1971.

14. Cairns, E. J., Gay, E. C., Shimotake, H., and Selman, J. R., Presentation: 1972 ISE meeting, Stockholm; see also extended abstract.

15. Liebhafsky, H. A., and Cairns, E. J., Fuel Cells and Fuel Batteries: A Guide to Their Research and Development, New York: Wiley, 1968.

16. Panel on Electrically Powered Vehicles, U.S. Dept. of Commerce, The automobile and air pollution: A program for progress, Part II, pp. 67-73, Dec. 1966.

17. Vielstich, W., Fuel Cells, Modern Processes for the Electrotechnical Production of Energy, New York: Wiley-Interscience, 1970.

18. Wyczalek, F. A., Frank, D. A., and Smith, G. E., A vehicle fuel cell system, SAE paper 670181.

19. "Target" Program, United Aircraft.

20. Podolny, W. H., Fuel cell powerplants for rural electrification, United Nations Rural Electrification Symposium, New Delhi, Dec. 1971.

21. Presentation of Army MERDC, Ft. Belvoir, to the Panel.

22. Marks, C., Rishavy, E. A., Wyczalek, F. A., Electrovan--A fuel cell powered vehicle, SAE paper 670176.

23. Kordesch, K. V., Hydrogen Air/Lead Battery Hybrid System for Vehicle Propulsion.

24. Gelb, G. H., Richardson, N. A., Wang, T. C., and Berman, D., SAE paper 710235.

25. Lapedes, D. E., Proc. Ind. Internal Elec. Vehicle Symp. Electric Vehicle Council, New York, 1971.

26. Barpal, I. R., 1971 IECEC, p. 842.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 17 1975

OFFICE OF THE
ADMINISTRATOR

Dear Mr. Chairman:

This is in response to the letter, dated April 28, 1975, from Mr. John L. Swigert, Jr., Executive Director of your Committee, requesting our views and recommendations with regard to H.R. 5470, a bill "To authorize in the Energy Research and Development Administration a Federal program of research, development, and demonstration designed to promote electric vehicle technologies and to demonstrate the commercial feasibility of electric vehicles."

The purpose of this proposed legislation is to demonstrate the commercial feasibility of electric vehicles for urban individual and business use, and to encourage research and development in new technologies for electric vehicles with wider applications, in order to promote long-range conservation of liquid fuel and reduce environmental pollution.

The Administrator of the Energy Research and Development Administration (ERDA) immediately upon passage of the legislation would be mandated to establish the Electric Vehicle Research, Development and Demonstration Project for which he would be responsible for the overall management. But he could enter into agreements with other Federal agencies, including the Environmental Protection Agency (EPA), for the conduct of certain aspects of the project which are within their particular competence.

Acting through appropriate agencies and contractors, the Administrator of ERDA would be required to initiate and provide for the conduct of research and development in areas related to electric vehicles, including (1) energy storage technology, including batteries and their potential for convenient recharging; (2) vehicle control systems and overall design for energy conservation, including the use of regenerative braking; (3) urban design and traffic management for optimum transportation-related energy use and minimum transportation-related degradation of the environment; and (4) vehicle design for maximum practical lifetime, ease of repair, and interchangeability and replaceability of parts.

In the demonstration area, it would be required that the Administrator enter into such contracts as are necessary and appropriate for the production of "significant numbers" (defined as 5,000 or more) of urban passenger and commercial vehicles (1) within one year which have electrical propulsion systems on conventional chassis, and (2) within three years which are specifically designed for electrical propulsion as the primary source. These vehicles would be required to meet the performance standards and criteria to be developed within 180 days for each of these two types of vehicles. Such standards and criteria would not simply reflect the characteristics of current combustion engine vehicles, but would have to take into account such factors as energy conservation, urban traffic characteristics, patterns of use for "second" vehicles, consumer preferences, maintenance needs, battery recharging characteristics, materials demand and recyclability, and vehicle safety and insurability. Appropriate authorities concerning design needs for electrical vehicles compatible with long-range urban planning and traffic management would have to be consulted in developing such standards and criteria.

The Administrator would also be charged with the responsibility of making arrangements for the introduction of such electrical vehicles into (1) the vehicle fleets of government agencies at all levels; and (2) individual and business use under conditions insuring widespread use; as well as for the evaluation of performance and consumer reaction, for model training projects on maintenance procedures, and for dissemination of data on safety and operating characteristics.

Further, the Administrator would be required to (1) conduct a study and report to Congress within six months on the existence of any tax, regulatory, traffic, urban design and other institutional factors which might bias transportation systems toward vehicles of particular characteristics; (2) conduct a continuing assessment of long-range materials demand and potential pollution effects of electrification of urban traffic; and (3) have studies made on incentives to promote broader utilization and consumer acceptance of electric vehicle technologies.

A semi-annual report to Congress would be required on all activities under the proposed Act with appropriate recommendations for further action.

An amount not to exceed $40,000,000 would be authorized to be appropriated for each of the fiscal years 1976, 1977, and 1978. Any amount appropriated would remain available until expended, and any amount authorized for either of the first two fiscal years, but not appropriated, could be appropriated through the third fiscal year.

While the Environmental Protection Agency endorses the need for intensive research on the feasibility of electric vehicles, it does not support the enactment of H.R. 5470 for the following reasons.

H.R. 5470 is an extremely comprehensive bill with very short deadlines in which to accomplish complicated research and various studies. By emphasizing the commercialization of electric vehicles prematurely, this bill might be detrimental in the long run if the currently available vehicles fail to live up to expectations as the solution to urban traffic problems.

Under the authorities of the Clean Air Act, EPA has gained substantial knowledge about electric vehicles. This resulted from our AAPS program (research, development, and demonstration of alternative automotive power systems) which was transferred to ERDA in January of this year, and from work carried out under Section 212 of the Act -- Development of Low-Emission Vehicles. To summarize, the major limiting factor on the use of electric vehicles is the current inadequacy of storage batteries. We, therefore, believe that Federal research should focus on the development of a battery with sufficiently high power and energy density to provide adequate vehicle range and road performance. The development of motors, chassis, controls, etc. could, and should, be left to industry.

Although there is some disagreement among independent analysts and electric car enthusiasts, EPA has concluded that electric vehicles constructed with existing technology do not represent an energy-efficient way for performing the types of transportation services which privately-owned automobiles are expected to perform. For example, a comparison between two equal-size vehicles of the four-passenger compact car category -- one powered by a conventional combustion engine and one by state-of-the art lead acid storage batteries -- shows roughly one-third greater energy consumption for the electric vehicle, over a typical city-suburban commute cycle. An exception to this would be applications such as milk delivery trucks, which encounter numerous stops and starts and relatively extended periods of engine idling.

Further, the pollution potential of the generation of electricity must be factored in and must be evaluated as an offset to the absence of HC, CO and NO_x emissions from the electric vehicle itself. The nature of this pollution, in turn, depends upon whether fossil or nuclear powerplants are used and where they are sited. That is not an easy balance to make, but it must not be ignored.

The EPA has been conducting analytical studies on the impact of future expanded use of electric cars in selected metropolitan regions, which are scheduled for completion later this year. The results of these studies may be expected to provide guidance as to the usefulness and direction of future Federal programs designed to encourage electric cars.

Since improved batteries are essential before an electric vehicle can be a viable substitute for the conventional internal combustion vehicle in urban areas, we believe that research priority should be directed toward that goal. Related problems can only be addressed realistically if that goal is achieved.

For these reasons, the Environmental Protection Agency recommends that a more desirable approach would be for ERDA to continue with the research program on an improved battery and to defer any decisions relating to demonstration and procurement programs until the battery technology is better developed.

The Office of Management and Budget has advised that there is no objection to the submission of this report from the standpoint of the Administration's program.

Sincerely yours,

John Quarles, Acting
Russell E. Train
for Administrator

Honorable Olin E. Teague
Chairman
Committee on Science and Technology
House of Representatives
Washington, D.C. 20515

Comments on H.R. 5470

Electric Vehicle Research, Development and Demonstration Act of 1975

Prepared for:

The Subcommittee on Energy Research,
Development and Demonstration
of the
House Committee on Science and Technology

By:

James C. Willyard
P. O. Box 9
Burtonsville, Maryland 20730

2 July 1975

I appreciate the opportunity to submit my comments on the proposed Bill H.R. 5470. First, I would like to voice my support for the Bill. I feel that it is consistent with our national and international objectives and that the approach to provide a near-term solution to a serious national problem is realistic. Second, I wish to reveal a revolutionary vehicle that lends itself to the use of electrical power.

Utilization of private and commercial vehicles is currently at a very high level. The utilization level is dictated, in large part, by the flexibility required by individuals and businesses in our fast-paced, demanding modern society. Public transportation, despite subsidies and increased rates, are finding it increasingly difficult to meet the tempo and diverse demands of the public in terms of routing, frequency, and volume.

Nearly all transportation vehicles are currently powered by the internal combustion engine. Approximately one-half of our total crude petroleum output is refined into gasoline to power these vehicles. Users of these vehicles are not afforded the choice of substitution as in the case of other goods and services. They are dependent upon petroleum as a source of energy - subject to the higher fuel prices, inconvenience and lack of fuel availability imposed by the market and an inflexible economic structure.

The demand for public and commercial vehicles and the utilization of these vehicles is likely to increase in the future. Our petroleum supply is not unlimited - therefore we must develop and apply other sources of energy. Failure to do so would require importing increasing amounts of petroleum. Petroleum-producing countries have exerted significant political and economic pressure on petroleum consuming nations. It is unlikely that increasing our petroleum imports would enhance our balance of payments, our position in the international community or our current role in international politics. This issue, and the growing gap between our own petroleum supply and demand, indicates the critical nature of the problem and why it is worthy of immediate serious thought and action with federal support.

The action proposed by H.R. 5470 would not only alleviate our dependence upon petroleum, but would stimulate competition between petroleum and electric generating economic sectors. The effect of this competition may reduce prices and inflationary trends in these two economic sectors and the sectors upon which they impact. The private forms of transportation, maintained by this Bill, would also effectively compete with public transportation systems tending to maintain rates at lower levels.

The Federal Government has, in the past, stimulated and supported various industries through tariffs, subsidies and development programs. H.R. 5470 appears to be realistic in terms of its timing, approach, purpose and goals. The technology appears to be reasonably developed in terms of the primary energy sources. Other components are currently available to enhance electric-powered vehicle performance. Groups submitting previous testimony have demonstrated a willingness to innovate and apply the products of their development programs. Government support in the latter stages of development and larger scale production allow electric-powered vehicles to be more competitive with those powered by petroleum in terms of initial price to the consumer. Additional legislation to develop other forms of energy must be introduced for longer range applications.

Previous testimony has been directed to the development and application of electric power to automobiles. I would like to address another type vehicle, namely boats. Application of electric power to these vehicles would provide diversity and flexibility in the development/demonstration program within a different set of environmental and operational conditions. Current water vehicles are relatively inefficient in their operation and require large amounts of power. Electric power applications are currently limited to small, slow speed fishing boats used for trolling.

Recently, I have developed a revolutionary configuration (described in the enclosed attachment), which increases efficiency significantly. The concept has been demonstrated in test models up to 14 feet in length; however, the full potential of this configuration has not yet been realized. Based on conservative projections from test results, this configuration requires only one-fourth the power of current designs. Power requirements may actually be one-eighth or less of that required for existing designs with similar performance.

Electric power applications to this vehicle appear very attractive. Small electric motors provide the necessary power to achieve acceptable speeds. Battery packs may be substituted for fuel and offer the following advantages over internal combustion engines:

1. More stable weight-balance characteristics. The center of gravity does not change as fuel is burned off.
2. Design flexibility in locating the battery packs and the motor.
3. Safety is enhanced. There is no danger of explosions of volatile fuel.

The configuration is analagous to the automobile in many respects - torquing requirements for the cylinder are similar to those for the automobile wheels. Therefore, components used in this water vehicle configuration can be transferred directly to the automobile and vice versa. The development/demonstration programs of these two vehicles could well complement each other.

The marine vehicles can be introduced into the fleets of government agencies. Candidate agencies are the Defense Department, Interior Department, Transportation Department and Harbor Patrols.

Mike McCormack, Chairman
Subcommittee on Energy Research
Development, and Demonstration
Suite 2321 Rayburn House Office Bldg.
Washington, D.C. 20515 june 27,1975

Dear Mr. McCormack: Re: Invitation to present written statment on Bill H.R. 5470

While it is true that the Gasoline Engine has been developed to a highly sophisticated state and is extremely versitile, never the less it is non competitive with electrics in terms of energy efficiency and non polluting means of transportation.

With the potential development of atomic to electrical energy direct conversion, all advantages of Gasoline vehicles would dissapear over night. The reliability of electric motors is well known. Simplicity of exchanging defective motors is also utter simplicity compared to Internal combustion engines.

It is only the limitations of Batteries that holds back Electric vehicles from over running the Gasoline engined vehicle. That may change over night. Some new discovery or development unknown of at this time but underway may be in the making of such power source and whatever developments are generated in Electric vehicles during this period of redevelopment will only add to the impetous of new energy sources and battery break throughs. One need only to remove the batteries and replace them with the new power source and over night progress is made.

The internal combustion engine, no matter what greater perfection is developed, still cannot compete with its 25% to 30% efficiency on converting energy to power, as compared with the 90% to 95% that is already possible with Electric Motors as energy to power convertors. The purpose of conserving energy from waste virtualy mandates the redevelopment of Electric cars with the advanced technology existing to day. We put men on the moon, we can perfect likewise transportation of safe, sane, non polluting nature.

Patent 3,809,978 resulted from accidental discovery of a new concept that indicates a 50% energy saving for electric vehicles adopting such system. Not only does this indicate double the milage possible from a set of batteries, but batteries last longer because they are not punished through excess power drain. Comp onents for control are of lighter requirement and last longer. Inventors such as myself are handicapped by the lack of research and development funds to fully exploit the potentialities of such discoveries; It is a problem to even sumit for consideration to private or goverment agencies such novel developments, when such novelty defies engineering analysis and recognition without testing.

Obviously to compete with the rest of the world, wether the party be a lonely inventor of unrecognized status or a mighty corporation it is only through Goverment support through such as Bill H.R.5470 that the resources of this country can be marshalled to face the challenges the Nation now faces.

sincerely
Joseph R. Zubris
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APPENDIX II

Additional Material for the Record

HD 9710 Gen. 75-75 SP

THE ELECTRIC VEHICLE -- AN ALTERNATIVE TO THE GASOLINE-POWERED CAR

CONGRESSIONAL RESEARCH SERVICE
LIBRARY OF CONGRESS

MAUREE W. AYTON
Analyst, Science and Technology
Science Policy Research Division

March 12, 1975

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I. INTRODUCTION

Last year, the gasoline crisis produced lines of cars at gasoline pumps waiting to be filled. This year, the need still remains to reduce the amount of gasoline that is consumed by cars. Because the American public depends on the car to such a great extent and because of our dependence on imported oil, alternative sources of energy to power our cars are sought. One such alternative is electricity as a power source for cars.

Petroleum would be saved only if the electricity used in charging the battery is generated by a power plant using a fuel other than petroleum. Contrary to a popular impression, the efficiency of an electric vehicle approaches that of a gasoline-powered vehicle. For example, the thermal efficiency (efficiency with which the energy in the fuel is converted into mechanical energy) of a gasoline-powered vehicle (4-cycle internal combustion engine, Otto cycle) is 28%. 1/ For an electric vehicle, the operating efficiency must take into account the fuel used to generate the electricity to charge the batteries. Power plant efficiencies average to about 35%. Other losses include power distribution losses, battery charging losses and electric motor efficiency. The accumulated losses would therefore place the electric vehicle in the same category as the conventional automobile engine as far as fuel efficiency is concerned.

1/ U. S. Office of Science and Technology. Energy Study Group. Energy R & D and National Progress. Prepared for the Interdepartmental Energy Study. Washington, U.S. Govt. Print. Off., 1964. p. 218.

Electric cars have been around for a long time. In the early 1900's in the United States, there were more electric cars than gasoline-powered cars on the road, but by the late 1920's, the electric car had almost disappeared. The electric car was unable to match the popularity of gasoline cars because of battery limitations. Few electric cars could travel more than 20 miles per hour and their batteries had to be recharged about every 50 miles.

The electric car has no transmission, radiator, or exhaust (to contribute to the pollution problem), makes almost no noise, and burns no oil or gasoline, yet it still cannot compete with a gasoline-powered car because of the battery problem.

This report discusses the advantages and disadvantages of electric vehicles, the state of the industry, as well as the legislative interest. It also includes a selected bibliography on electric vehicles.

II. ADVANTAGES AND DISADVANTAGES OF ELECTRIC VEHICLES

The oil embargo and our growing shortages of petroleum have caused renewed interest in the electric vehicle as an alternative to gasoline-powered vehicles. However, there are disadvantages as well as advantages involved with the electric vehicle. Nelson, reporting at the International Electric Vehicle Symposium, points out that --

> The minimum requirements for a viable electric-car battery are those set by an electric commuter car having a range of about 100 miles and performance comparable to that of a small gasoline-powered car. However, existing batteries fall far short of the requirements even for this moderate service. It is expected that small electric commuter cars could penetrate the automobile market to the extent of 20% of sales and 10% of the cars on the road by the year 2000. It is unlikely that electric cars will replace the large automobile or trucks and, therefore, the effect on the economy of the introduction of electric cars will be gradual and moderate. Although these effects would be moderate, they would be beneficial to the national interest. 2/

A. Advantages

Electric vehicles have the advantages of being relatively noiseless, and are "virtually nonpolluting, but the electric power generating plants providing the electric energy do cause pollution. However, by the use of pollution control equipment and tall stacks at coal-burning power plants, the equivalent ground-level emissions for the electric-car system are reduced by at least one order of magnitude for all of the

---

2/ Nelson, P.A., and Others. (Argonne National Laboratory) ANL High-energy Batteries for Electric Vehicles. Paper Presented at the Third International Electric Vehicle Symposium and Exposition, Washington, D.C., Feb. 19-21, 1974. p. 1.

important pollutants." 3/

The electric vehicle could be very useful as a second car in a family for in-town driving, for shopping, or for any short trips on the city streets. Nelson points out that--

> The development of economically competitive electric automobiles would reduce the demand for oil and, thus the need for oil imports. The introduction of electric cars by about 1985 and a gradual build-up to a total of 18,000,000 cars on the road by the year 2000 would result in a cumulative savings of petroleum of 1.3 billion barrels by replacement of gasoline cars driven 10,000 miles per year at 20 miles per gallon (see table 1). The annual savings at that time would be about 270 million barrels of oil per year. Although this is a small fraction of the projected crude oil requirement for transportation in the year 2000, this extent of savings could be important in reducing the need for oil imports. 4/

TABLE 1

Impact of Electric Automobiles on U. S. Petroleum Consumption 5/

	No. of Electric Cars		Cumulative Car-Years	Petroleum Saved[a]	
	Produced	In Use		Cumulative Barrels[b]	Value,[c] $Million
1982	1×10^3				
1985	1×10^5	2×10^5	3×10^5	4.5×10^6	27
1990	1.5×10^6	1.8×10^6	5.5×10^6	8.2×10^7	490
2000	5×10^6	1.8×10^7	8.5×10^7	1.3×10^9	7800

[a] Assumes electricity generated by means other than burning oil.

[b] Savings of 15 barrels of petroleum per year of gasoline-powered car operation, assuming 80% conversion of petroleum to gasoline (or product of equivalent value), and car utilization of 10,000 miles/yr at 20 miles/gal of gasoline.

[c] Average cost of petroleum, $6/barrel.

3/ Mencher, Simon K., and Howard M. Ellis. (Gordian Associates, Inc.) The Comparative Environmental Impact in 1980 of Gasoline-powered Motor Vehicles versus Electric-powered Motor Vehicles: a Summary of Results. In Proceedings of the Second International Electric Vehicle Symposium, Held in Atlantic City, N.J., Nov. 8-10, 1971. New York, Nov. 1971. p. 764-765.

4/ Ibid., Nelson, P.A.

5/ Ibid., Nelson, P.A., p. 3.

B. Disadvantages

At the present time, the electric vehicle does not have enough electrical storage capacity to give it the same range and performance as a vehicle burning gasoline. The central problem is the lack of availability of batteries with sufficiently high specific energy and specific power. 6/

Other disadvantages include the heavy weight of the lead-acid batteries found in most electric vehicles, the danger of acid spillage resulting from bad accidents, battery life, and the bother and time requirement for recharging. Wide usage would presuppose a system (probably quite expensive) for servicing and recharging the vehicles which is not now in existence.

6/ National Academy of Sciences. Committee on Motor Vehicle Emissions. An Evaluation of Alternative Power Sources for Low-emission Automobiles. Report of the Panel on Alternate Power Sources to the Committee. Washington, Apr. 1973. p. 68.

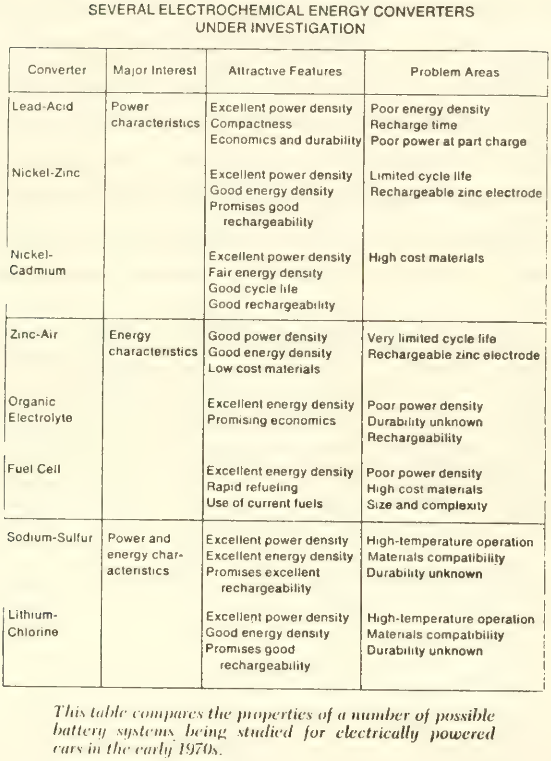
III. BATTERIES

Batteries for electric vehicles have several requirements including low cost, high power delivery capability (expressed in specific power, watts per pound) and high energy storage capability (expressed in specific energy, watt-hours per pound). This means that the ideal battery system should (1) be inexpensive; (2) be able to provide a very high level of power for short periods of time for very little battery weight to enable the car to go to cruise speed from a stop position or for fast acceleration to pass another car on the road; and (3) have a great deal of energy in a lightweight package to provide a continuous supply of power that will permit the car to travel a reasonable distance without recharging.

Research has been carried out on various types of batteries for electric cars. The following table 7/ shows several battery systems for electrically-powered cars that were being studied in the early 1970s.

7/ Stambler, Irwin. Automobile Engines of Today and Tomorrow. New York, Grosset and Dunlop, 1972. p. 94.

TABLE 2



SEVERAL ELECTROCHEMICAL ENERGY CONVERTERS UNDER INVESTIGATION

Converter	Major Interest	Attractive Features	Problem Areas
Lead-Acid	Power characteristics	Excellent power density Compactness Economics and durability	Poor energy density Recharge time Poor power at part charge
Nickel-Zinc		Excellent power density Good energy density Promises good rechargeability	Limited cycle life Rechargeable zinc electrode
Nickel-Cadmium		Excellent power density Fair energy density Good cycle life Good rechargeability	High cost materials
Zinc-Air	Energy characteristics	Good power density Good energy density Low cost materials	Very limited cycle life Rechargeable zinc electrode
Organic Electrolyte		Excellent energy density Promising economics	Poor power density Durability unknown Rechargeability
Fuel Cell		Excellent energy density Rapid refueling Use of current fuels	Poor power density High cost materials Size and complexity
Sodium-Sulfur	Power and energy characteristics	Excellent power density Excellent energy density Promises excellent rechargeability	High-temperature operation Materials compatibility Durability unknown
Lithium-Chlorine		Excellent power density Good energy density Promises good rechargeability	High-temperature operation Materials compatibility Durability unknown

This table compares the properties of a number of possible battery systems being studied for electrically powered cars in the early 1970s.

FROM: Stambler, Irwin. Automobile Engines of Today and Tomorrow. New York, Grosset and Dunlop, 1972. p. 94.

The lead-acid battery that has been used almost entirely to power electric vehicles has been found to be rugged, efficient, reliable, and immediately responsive to large changes in load. Other rechargeable batteries, "such as zinc/silver-oxide and cadmium/nickel-oxide, while superior in some respects to the lead-acid system, are inherently unsuitable for vehicular applications because of cost and/or limited availability of materials." 8/ It is also pointed out that "the zinc/nickel-oxide battery is expected to allow a vehicle design with acceptable acceleration and a range of about 80 miles between recharges." 9/

The study by the National Academy of Sciences indicates that --

> The most promising of the advanced battery systems are sodium/sulfur and lithium/sulfur batteries, which operate at temperatures in the range 300-400 C, and are maintained at operating temperature by their reject heat and appropriate thermal insulation. These batteries are expected to have specific energies of 100 watt-hours per pound and specific powers of 100-200 watts per pound, permitting the design and construction of electric vehicles with excellent acceleration capabilities and a range of about 200 miles between recharges. About 7 to 8 years of optimum effort will probably be required for the development of pilot quantities of these batteries for vehicle test purposes. 10/

The following table shows characteristics of various batteries and electric vehicles.

8/ National Academy of Sciences. Report by the Committee on Motor Vehicle Emissions... between the Environmental Protection Agency and the National Academy of Sciences. Washington, Feb. 12, 1973. p. 109.

9/ Ibid.

10/ Ibid.

TABLE 3

Characteristics of Batteries[a] and Electric Vehicles

Battery *	Electrolyte	* Operating Temp. °C	Specific Energy w-hr/lb[a]	Peak Specific Power w/lb[b]	Range,[c] Miles	Acceleration	Cycle Life	Cost[f] \$/kw-hr	Status	Time Dev. Year
Pb/PbO2	H_2SO_4(aq)	Ambient	10-20	75	20-40	Fair	300	20-50	Available	--
Cd/Ni_2O_3	KOH(aq)	Ambient	10-20	150	20-40	Excellent	1000	>150	Available	--
Zn/Ni_2O_3	KOH (aq)	Ambient	25-35	100	40-80	Good	(300)	>100	Laboratory cells and batteries	4
Zn/Ag_2O	KOH(aq)	Ambient	40-55	100	80-100	Good	100	>400[e]	Available	--
Li(Al)/ $TeCl_4$ (C)	LiCl-KCl	360-500	(50-60)	(120-150)	90-110	Excellent	(1500)		~1 kwh prototype batteries	5
Na/S	$Na_2O.xAl_2O_3$ or glass	300-350	(80-100)	75-100	150-200	Good	(1000)	(10-30)	~1 kwh lab batteries	7
Li/S	LiCl-KCl	375-400	(100-120)	(100-200)	(200-240)	Excellent	(1000)	(10-30)	Small lab batteries, sealed cells	8

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[a] Figures in parentheses are estimates for the future, based on present laboratory data.

[b] Urban-suburban driving profile average power level.

[c] Urban-suburban driving requires peak power, at least 70 w/lb, with 100 w/lb preferred.

[d] Urban-suburban driving profiles.

[e] Deep discharge.

[f] Authors' estimate; includes allowance for salvage value.

[g] \$/kw-hr of energy storage capability (one cycle).

* See next page for translation of chemical terms.

FROM: National Academy of Sciences. An Evaluation of Alternative Power Sources for Low-Emission Automobiles. Report of the Panel on Alternate Power Sources to the Committee on Motor Vehicle Emissions. Washington, Apr. 1973. p. 73.

* From preceding page.

BATTERY		ELECTROLYTE	
Pb/PbO_2	(Lead-Lead oxide)	H_2SO_4 (aq)	(Sulfuric acid (aqueous))
Cd/Ni_2O_3	(Cadmium-Nickelic oxide)	KOH (aq)	(Potassium hydroxide (aqueous))
Zn/Ni_2O_3	(Zinc-Nickelic oxide)	KOH (aq)	(Potassium hydroxide (aqueous))
Zn/Ag_2O	(Zinc-Silver oxide)	KOH (aq)	(Potassium hydroxide (aqueous))
$Li(Al)/TeCl_4$	(Lithium (Aluminum-Tellurium tetrachloride)	LiCl-KCl	(Lithium chloride-Potassium chloride)
Na/S	(Sodium-Sulfur)	Na_2O x Al_2O_3	(Sodium monoxide x Aluminum oxide)
Li/S	(Lithium-Sulfur)	LiCl-KCl	(Lithium chloride-Potassium chloride)

IV. MARKET POTENTIAL

The electric vehicle industry is very small at this time, and the rate of increase of road vehicles is negligible compared with the number of gasoline-powered vehicles on the road.[11] However, in 1972, before the real gasoline crisis occurred, the Electric Vehicle Council, an industry association, commissioned a market study which showed that 42% of the people in this country would be interested in buying a short-range limited-speed electric car if one were available for less than $2,000. This car would be used for traveling around town, would have a top speed of about 40 miles per hour and would travel about 150 miles before the batteries needed recharging.

The Electric Vehicle Council also pointed out that "the percentage of people who would be interested in such a car is steadily increasing. In a similar survey made in 1970, 39% of the public said it would be interested in having an electric car, while in 1967, it was 32%." [12]

In another study made by the Electric Vehicle Council and the Copper Development Association "of a realistic estimate of the number of vehicles on America's streets and highways in the early 70's which could perform their regular functions with electric power," it was found that "as many as 20.5 million passenger cars and light trucks could function as electric vehicles." The Federal Power Commission's National Power Survey forecasts 38-million, on-the-road electric vehicles by 1990.[13]

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[11] Private Communication, Electric Vehicle Council.

[12] Electric Vehicle Council. Fact Sheet on Electric Transportation. New York [1972] p. 1.

[13] Ibid.

The Electric Vehicle Council also indicated that --

> The possibility of a proliferation of electric vehicles has raised concern about the effect of these electrics on the energy supply and the environment. However, studies made by a number of electric utility companies indicate that the electric vehicles' demand would come primarily during off-peak hours and would not significantly increase the capacity requirements of utilities. With a 1990 market of 38 million electric automobiles, if only one-half of that market were to develop, the annual consumption of electric energy for recharging batteries could reach about 62 million megawatt-hours a year. While this electric load would be equivalent to about 1% of the total electric energy production in 1990, it would probably have little effect upon peak demands because most of the cars would be in use during normal peak demand periods while the batteries would be recharged during the night when system demands are low. 14/

14/ Ibid., p. 2-3.

V. PROGRAMS

Programs to develop and test or to carry out research on electric vehicles or on batteries in the United States are being carried out by the following:

U. S. Department of Transportation -- Has made a grant to Lansing, Michigan, for the demonstration and testing of electric buses.

U. S. Energy Research and Development Administration (Work on Advanced Automotive Power Systems was transferred from the U. S. Environmental Protection Agency (EPA)). -- EPA awarded contracts in 1973 and 1974 to determine the environmental, energy, social, and economic impact of the electric car in California, St. Louis, Missouri, and Philadelphia, Pennsylvania. The EPA felt that "if the limited performance electric car were to be used in reasonable numbers in this country, they probably would do so only in particular localities.") 15/

U. S. National Science Foundation -- Its Research Applied to National Needs (RANN) program has funded battery research since 1971, with potential application to ground propulsion systems.

U. S. Postal Service -- Testing of electric vehicles for mail delivery.

Electric Vehicle Council -- Involved in the manufacture, purchase, and operation of electric work vehicles.

In addition, several companies and electric utilities have also built experimental electric vehicles. Electric cars are available in limited supply. The Directory of the Electric Vehicle Industry 16/ lists the following U. S. firms:

(1) Passenger cars, on-the-road, less than 2,000 pounds (with batteries)

B & Z Electric Car, Long Beach, California

Club Car, Inc., Augusta, Georgia

15/ Energy Users Report, 1974: 51:1004.

16/ Electric vehicle news, Feb. 1975: 26.

Elcar Corporation, Elkhart, Indiana

Elektra Associates, Inc., Houston, Texas

Otis Elevator Co. - Diversified Operations, Cleveland, Ohio

Otis Elevator Co. - Special Products Div., Stockton, California

Power-Ped, Inc., Virginia Beach, Virginia

Sebring-Vanguard, Inc., Sebring, Florida;

(2) Passenger cars, on-the-road, 2,000 pounds or more (with batteries)

Autodynamics, Inc., Marblehead, Massachusetts

Electric Fuel Propulsion Corporation, Ferndale, Michigan

Electromotion, Bedford, Massachusetts

Hellectric, La Jolla, California

McKee Engineering Corporation, Palatine, Illinois

Otis Elevator Co. - Diversified Operations, Cleveland, Ohio

Otis Elevator Co. - Special Products Div., Stockton, California

Petro-Electric Motors, Ltd., New York, New York

C.H. Waterman Industries, Athol, Massachusetts

In recent testimony at House hearings 17/ a spokesman from the U.S. Environmental Protection Agency (EPA) pointed out that EPA is "currently exploring the feasibility of all-electric vehicles as a candidate for future Federal support, an alternative that could hold special promise for acute problem areas such as California's South Coast Basin." The EPA spokesman also indicated that --

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17/ U.S. Congress. House. Committee on Science and Astronautics, Subcommittee on Space Science and Applications. Research on ground propulsion systems. Hearings, 93d Congress, 2d session. Washington, U.S. Govt. Print. Off., 1974. p. 87.
Hearings held Feb. 4, 5, 6, 1974.

> If high energy density, high power density batteries were to be needed for automotive use, they would have to be developed. They do not exist today. We believe it would be a Federal program, and it would take 8 to 10 years and cost a lot of money. We are currently making a study on the basis of which we might recommend such a development program. But the point is not should a battery be developed or not. The point is, can you safely use electric vehicles in a mix with gasoline-powered vehicles, and second, where are you going to get the energy to charge those vehicles? There [are] data that suggests that energy is already in very short supply and no one knows how electricity is going to be supplied by the year 2000 to meet existing demands, not to mention transportation demands. So there is no sense in having a Federal program to develop batteries unless there can be some confidence you are going to be able to generate the electricity to charge those batteries. We are looking at things like how long will it take for nuclear energy to be able to charge batteries as well as safety factors on battery cars. If only electric power in terms of safety is a useful way of solving our transportation problem, only then would we recommend the battery development program. [18]

Other research on batteries for electric vehicles has been carried out by the Army Electronics Command, Fort Monmouth, N. J., Argonne National Laboratory, Ill., and by the National Science Foundation through grants under the Research Applied to National Needs (RANN) program.

In the private sector, battery research has been done by several companies, including ESB, Inc., Electric Fuel Propulsion Corporation, General Battery Corporation, and Gould, Inc.

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[18] Ibid., p. 99-100.

VI. LEGISLATION

In the 94th Congress, there has been a great deal of interest in programs that would explore the feasibility of various alternative engines. The following bill has been introduced that relates specifically to electric vehicles:

H. R. 5470. To authorize in the Energy Reserch and Development Administration a Federal program of research, development, and demonstration designed to promote electric vehicle technologies and to demonstrate the commercial feasibility of electric vehicles. Messrs. McCormack, Brown (Calif.), Teague, Mosher, and Goldwater. Mar. 25, 1975. To Committee on Science and Technology.

In addition, the following bills have also been introduced that would relate to electric vehicles -- ground propulsion systems (i.e., the engine, transmission, or drive, and associated controls, necessary to power automobiles, trucks, trains, buses, and selected light marine vehicles):

S. 783. To authorize a Federal program of research and demonstration in connection with ground propulsion systems. Messrs. Domenici, Baker, and Glenn. Feb. 20, 1975. To Committee on Commerce.

H.R. 738. To amend the National Aeronautics and Space Act of 1958 to authorize and direct the National Aeronautics and Space Administration to conduct research and to develop ground propulsion systems which would serve to reduce the current level of energy consumption. Jan. 14, 1975. Mr. Murphy (N.Y.) To Committee on Science and Technology.

Identical bill: H.R. 891. Mr. Price. Jan. 14, 1975.

H.R. 1109. To authorize the Administrator of the Energy Research and Developmment Administration (ERDA) to undertake a program of research and development for demonstrating alternative propulsion systems for automotive vehicles. Mr. Teague. Jan. 14, 1975. To Committee on Science and Technology.

H.R. 5557. To authorize the Administrator of the Energy Research and Development Administration to undertake, in cooperation with the National Aeronautics and Space Administration, and other Federal agencies, a program of research, development, and demonstration of ground propulsion systems which would serve to reduce the current level of energy consumption. Mr. Brown (Calif.) Mar. 26, 1975. To Committee on Science and Technology.

To date, no action has occurred on any of these bills. It is expected that other bills will be introduced that will also include electric vehicles.

VII. SELECTED REFERENCES

Ayres, Robert U., and Richard P. McKenna. The electric vehicle. In Alternatives to the internal combustion engine; impacts on environmental quality. Baltimore, The Johns Hopkins University Press for Resources for the Future, Inc., 1972. p. 206-229.

Beardsley, Charles. Wanted: superbatteries. IEEE spectrum, July 1972: 42.

Bohn, Joseph J. 3 electric cars ready to test U. S. market. Automotive news, Aug. 12, 1974: 25-26.

Brooman, Eric W., John E. Clifford, and Donald E. Semones. Batteries: prospects for electric vehicles. Automotive engineering, Jan. 1975: 30-35.

Connolly, Ray. Electric vehicles draw interest. Electronics, Mar. 7, 1974: 70, 72.

Davis, P. Australians pioneer new electric car ideas. Popular science, Nov. 1974: 83.

The Electric-Vehicle group at Flinders University in South Australia has concluded "that the battery is not the only thing to concentrate on. There's a lot that can be done with the motors and the control system, as well as in basic vehicle engineering. The prototype combines the constant-speed printed-circuit electric motor and the hydrostatic transmission. The prototype is being tested, and the engineers expect to achieve a range of 50-90 miles, with a maximum speed of 40 mph with a 5-kilowatt motor, or 60 mph with a 10-kw motor.

Directory of the electric vehicle industry. Electric vehicle news, Feb. 1973: 19-34.

The electric car and the city center. In Transportation in the world of the future, by Hal Hellman. New, revised edition. New York, M. Evans and Company, 1968, 1974. p. 90-111.

The electric engines. In Automobile engines of today and tomorrow, by Irwin Stambler. New York, Grosset and Dunlap, 1972. p. 92-110.

The electric vehicle. In Alternatives to the internal combustion engine; impacts on environmental quality, by Robert U. Ayres, and Richard P. McKenna. Baltimore, The Johns Hopkins University Press for Resources for the Future, Inc., 1972. p. 206-229.

Electric Vehicle Council. Electric vehicles, a bibliography. New York, Electric Vehicle Council, 1970. 218 p.

Electric Vehicle Council. Proceedings of the first international electric vehicle symposium, held Nov. 5-7, 1969, in Phoenix, Ariz. New York, Nov. 1969. 552 p. Publ. No. 69-1000.

Electric Vehicle Council. Proceedings of the second international electric vehicle symposium, held Nov. 8-10, 1971, in Atlantic City, N. J., New York, Nov. 1971. 777 p. Publ. No. 72-1000.

Electric Vehicle Council. Proceedings of the third international electric vehicle symposium, held Feb. 19-21, 1973, in Washington, D. C., New York, 1973. Various papers.

Electrically driven vehicles. In An evaluation of alternative power sources for low-emission automobiles. Report of the Panel on Alternate Power Sources to the Committee on Motor Vehicle Emissions, Washington, National Academy of Sciences, Apr. 1973. p. 65-86.

Electrics get key Post Office tests. Electrical world, Nov. 1, 1973: 116-117.

EV revival: a full-issue review of electric vehicle technology. Special report. Machine design, Oct. 17, 1974: entire issue.

Farell, William F. EV 'Dash has dashed right into the hearts of the people of Long Beach. Electric vehicle news, v. 3, Nov. 1974: 10-13.

Fuchs, John. Electric cars: the switch on. Motor trend, Apr. 1974: 94+.

Graumlich, A. J., and C. V. Kern. ABC's of small electric vehicles. Automotive engineering, Sept. 1974: 58-69.

Healy, Timothy J. The electric car: will it really go? IEEE spectrum, Apr. 1974: 50-53.

Hellman, Hal. The electric car and the city center. In Transportation in the world of the future. New, revised edition. New York, M. Evans and Company, 1968, 1974. p. 90-111.

Hoffman, George A. The electric automobile. Scientific american, Oct. 1966: 34-40.

Hoffman, George A. Future electric automobiles. Technological forecasting, v. 1, 1969: 173-183.

Little, Arthur D., Inc., Cambridge, Mass. Prospects for electric vehicles. A study of low-pollution-potential vehicles - electric. Oct. 1969. 96 p. Prepared under contract no. PH 86-67-108 between the National Air Pollution Control Administration and Arthur D. Little, Inc. PB 194 814

National Technical Information Service. Electric automobiles; a bibliography with abstracts. Springfield, Virginia, Oct. 1974. 71 p. Rept. No. COM-74-11573.

Netschert, Bruce C. The economic impact of electric vehicles: a scenario. Bulletin of the atomic scientists, May 1970: 29-35.

Norbye, Jan P. Clever engineering brings the electric car closer to your driveway. Popular science, June 1974: 40+.

Overbeke, James E. Electric vehicle industry sounds a 'charge.' Industry week, June 3, 1974: 42, 44-47.

Pashdag, John. Charge. A state of the art report and a most unusual road test of some electric vehicles. Motor trend, Mar. 1975: 60-63, 108.

Port, Frederick J. To make electric cars a reality in the U.S.A. help from utilities and government is needed. Electric vehicle news, Feb. 1972: 22-23.

Read, E.C. Motive power applications. Edited remarks. Electric vehicle news, May 1973: 22-23.

Reid, William T. The electric automobile. Battelle energy prespectives, no. 9, Apr. 1974: 1-5.

Salihi, Jalal T. Two for the road. IEEE spectrum, July 1972: 43-47.

Schaeper, H.R.A., and Erich A. Farber. University of Florida electric automobile. Paper presented at the American Society of Mechanical Engineers winter meeting, Nov. 28 - Dec. 2, 1971, in Washington, D.C. New York [1971] 8 p. [ASME Publication No. 71-WA/Sol-4]

Schwartz, Harvey J. Electric vehicle battery research and development. Electric vehicle news, Feb. 1974: 48-49.

Searle, Charles. Feasibility of electric taxis and buses in New York City. [ALbany] State of New York Public Service Commission, 1973. 42, 10 p.

Stambler, Irwin. The electric engine. In Automobile engines of today and tomorrow. New York, Grosset and Dunlap, 1972. p. 92-110.

Switching on electric vehicles. Environmental science and technology, May 1974: 410-411.

Teresko, John. A boom on the horizon for battery-powered transportation? Industy week, v. 182, Aug. 12, 1974: 48, 50, 53-54, 56.

Unnewehr, Lewis E., D.R. Hamburg, and L.R. Foote. How Ford evaluates three types of electric vehicles. Automotive engineering, June 1974: 37-41+.

U.S. Congress. Senate. Committee on Commerce. Automotive research and development and fuel economy. Hearings, 93d Congress, 1st session, on S. 1055 and S. 1903. Washington, U.S. Govt. Print. Off., 1973.
Hearings held May 3, 4, 14; June 8, 14, and 21, 1973. "Serial No. 93-41"

U.S. Congress. Senate. Committee on Commerce and the Subcommittee on Air and Water Pollution, Committee on Public Works. Electric vehicles and other alternatives to the internal combustion engine. Joint hearings, 90th Congress, 1st session, on S. 451 and S. 453. Washington, U.S. Govt. Print. Off., 1967. 550 p.
Hearings held Mar. 14, 15, 16, 17, and Apr. 10, 1967.

U.S. Congress. Senate. Committee on Public Works. Panel on Environmental Science and Technology of the Subcommittee on Air and Water Pollution. Alternatives to the gasoline-powered internal combustion engine. Hearing, 92d Congress, 2d session. Washington, U.S. Govt. Print. Off., 1972. p. 107-132.
Hearing held Mar. 14, 1972.
"Serial No. 92-H33"

U.S. Department of Commerce. The automobile and air pollution: a program for progress. Report of the Panel on Electrically Powered Vehicles. Washington, U.S. Govt. Print. Off., Oct. 1967. Part I, 51 p.; Part II, 160 p.

U.S. Federal Power Commission. Bureau of Power. Development of electrically powered vehicles. Prepared at the request of the Committee on Commerce, U.S. Senate. In U.S. Congress. Senate. Committee on Commerce and the Subcommittee on Air and Water Pollution, Committee on Public Works. Electric vehicles and other alternatives to the internal combustion engine. Joint hearings, 90th Congress, 1st session on S. 451 and S. 453. Washington, U.S. Govt. Print. Off., 1967. p. 11-62.

U.S. Public Health Service. National Center for Air Pollution Control, Cincinnati, Ohio. Power systems for electric vehicles. A symposium sponsored by the U.S. Department of Health, Education, and Welfare, Columbia University, and Polytechnic Institute of Brooklyn. Cincinnati, Ohio, 1967. 323 p.

Whiting, C.R. Let's mass produce an electric car now. Science digest, Aug. 1971: 67-71.

Wouk, Victor. Clean cars go to clean air. Electric vehicle news, May 1973: 16-20.

CRS - 22

Yearsley, Ian. Trams are coming back. New scientist, v. 56, Dec. 21, 1972: 699-701.

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THE NEED FOR DEVELOPMENT OF HIGH-ENERGY BATTERIES FOR ELECTRIC AUTOMOBILES

by

P. A. Nelson, A. A. Chilenskas,
and R. K. Steunenberg

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

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Chemical Engineering Division

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ABSTRACT

The development and economical production of batteries for powering small commuter cars would give electric cars an important place in the automobile market of the future. Electric cars would reduce the demand for oil, provide more efficient utilization of energy resources, and contribute to alleviation of air pollution. This report describes the requirements of a battery for powering an electric car having a range of about 100 miles and adequate performance for short-range driving. Estimates are presented of the potential savings in resources that could be made in the next twenty-five years through the use of small electric cars, and projections are given of the decreases that could be achieved in air pollution.

The report also discusses the program that is being conducted at Argonne National Laboratory to develop a high-temperature (400°C) lithium/sulfur battery of high specific energy and high specific power; this battery shows promise of meeting the requirements for the electric-vehicle application. The electrically rechargeable cells now being studied at ANL have positive electrodes of iron sulfide (FeS_2 or FeS), negative electrodes of a solid lithium-aluminum alloy, and an electrolyte of LiCl-KCl. Engineering-scale cells with FeS_2 positive electrodes have achieved maximum specific energies of 150 W-hr/kg, a value that meets the specific-energy goal set for the battery. The program also includes plans for transferring the technology developed at ANL to battery manufacturing firms.

SUMMARY

Electric automobiles would have an important place in the transportation field if an economical battery of high specific energy and high specific power were available. Such batteries would be most suitable for small commuter cars having a range of about 100 miles and performance comparable to small gasoline-powered cars. Existing batteries fall far short of the requirements of this service. It is expected that small electric cars of this type could penetrate the automobile market to the extent of 20% of sales and 10% of the cars on the road by the year 2000. It is unlikely that electric cars will replace the large automobiles or trucks and, therefore, the effect on the economy of the introduction of electric cars will be gradual and moderate.

Although these effects would be moderate, they would be beneficial to the national interest. The development of economically competitive electric automobiles would reduce the demand for oil and thus the need for oil imports. The introduction of electric cars by about 1985 and a gradual buildup to a total 18,000,000 cars on the road by the year 2000, would result in a cumulative savings of petroleum of 1.3 billion barrels (assuming replacement of gasoline cars driven 10,000 miles/year at 20 miles/gal). Electric automobiles would be more efficient in utilization of energy resources. If the energy is derived from coal, only one half as much coal would be required to produce electricity and recharge electric automobile batteries as would be needed to produce synthetic crude and gasoline for internal-combustion-engine automobiles.

The amount of electric energy required for the projected rate of market penetration for electric cars would be less than 1% of the total electric energy generated in the year 2000. Because batteries could be recharged at night, the load leveling resulting from this method of recharging would permit more extensive use of efficient base-load electrical generating stations, and thereby, would reduce the need for intermittently used peaking plants which are less efficient in use of fuel. Electric cars themselves would be virtually nonpolluting, but the electric power plants providing the electric energy do cause pollution. However, by the use of pollution-control equipment and tall stacks at coal-burning power plants, the equivalent ground level emissions for the electric-car system would be lower than those for the gasoline-car system by at least one order of magnitude for all of the important pollutants.

Even though the development of electric car batteries appears to be both beneficial to the national and economically attractive in the long range, such a development program may not be attractive to private industry because it is excluded by profit economics. The studies are expensive because they require inert-atmosphere gloveboxes which slow the work and increase the cost. A private firm would not receive a return on such a development program until at least 1985. Also, the technology for high-temperature type batteries that appear most promising is foreign to the development work normally carried out by battery manufacturers. On the other hand, the types of research on liquid-metal and molten-salt systems that have been conducted at Argonne National Laboratory (ANL) closely related to the high temperature battery technology.

High-energy batteries, such as the high-temperature battery now under development at Argonne National Laboratory show promise of meeting the requirements for a small electric automobile. A rechargeable, hermetically sealed (welded) cell of the type Li-Al/LiCl-KCl/FeS_2 has achieved a maximum specific energy of 155 W-hr/kg and has attained 110-135 W-hr/kg over 111 cycles and 2137 hr of operation. By reducing the weight of some of the components and improving the method of construction of the cells, it appears possible to build a battery with a specific energy of 150 W-hr/kg and a peak specific power of 200 W/kg. A battery with these characteristics, weighing 230 kg ($\sim$500 lb) and storing 35 kW/hr, would power a 1275-kg ($\sim$2800-lb) car at speeds and acceleration rates commensurate with gasoline cars and would provide a range of 100 miles. The production of an economically competitive battery of this type would assure the electric automobile of a place in the transportation field.

I. INTRODUCTION

If electric automobiles were economically attractive, battery manufacturers and automobile companies would both be eager to develop such vehicles, especially since their development might relieve the national energy problem. Why, then, should a national laboratory become involved in developing batteries for electric cars? The answer to this question lies in the special nature of the battery required for this demanding application, the expense and risk involved in the effort, the long period of time required before recovery of the investment, and the economic nature of the automobile industry.

The development of electric cars has been limited by the moderate power and energy storage capabilities of existing batteries. Because of the stringent battery performance requirements for transportation applications, development of batteries at Argonne National Laboratory (ANL) is directed toward requirements of small urban electric cars having a driving performance similar to that of other small cars, but a range of only about 100 miles. Such automobiles would fill an important need, since 75% of the total mileage for automobiles in this country is accumulated on trips of less than 50 miles.[1]

As illustrated in greater detail in a later section, a battery for a small electric automobile should have a specific energy of about 150 W-hr/kg and a peak specific power of about 200 W/kg and should cost the customer no more than about $20-$25 per kilowatt hour of storage capacity. These requirements far exceed the capabilities of any existing battery system (lead-acid batteries provide 25 to 40 W/hr-kg). Various investigators have concluded that these requirements can only be met by high-temperature batteries utilizing negative electrodes of an alkali metal or aluminum.[2,3] Although small development efforts on such batteries are under way by battery manufacturers (see Appendix A), the technology required for the study of these systems is foreign to the development work normally carried out by battery manufacturers. On the other hand, development by the national laboratories of several types of nuclear reactors, and of the technology underlying these reactors, has provided a wide range of expertise in liquid-metal and molten-salt systems.[4-7] Even more closely related to the type of research required for development of high-temperature automobile batteries are the studies that have been conducted at Argonne National Laboratory on a variety of electrochemical cells utilizing molten salts and liquid metals.[3,8-16]

One complicating factor involved in the research efforts to develop high-temperature batteries (which would not necessarily affect the utility of a fully developed battery) is the sensitivity of the constituents comprising the electrodes and electrolytes to moisture, oxygen, and nitrogen in the atmosphere. This sensitivity requires the use of inert-atmosphere gloveboxes for study of these systems and thus slows the work and increases the cost of the development effort by about a factor of three. Even under these circumstances, however, the cost of developing a prototypic battery that meets all of the requirements for an electric car is estimated to be only about $20,000,000; this amount is a fraction of 1% of the annual sales predicted for batteries suitable for electric vehicles and of the value of the oil that would otherwise be burned as fuel. If a private firm were to invest in such a venture immediately and carry it to the prototype stage by

1980, the return on the firm's investment could not be realized until about 1985, because of the delay required for development of manufacturing techniques. The present-worth factor for profits in 1985 is less than 10% and, therefore, this type of development program would tend to be excluded by profit economics, even though significant long-range benefits would be provided to the nation.

Other countries have encountered similar problems in funding the development of electric automobiles, despite an even greater incentive than that of the U.S. because of their dependence on foreign sources of oil. One such example is Japan. That country, in which private industry developed the first marketable car with a rotary engine, has found it necessary to provide govenment support for the development of electric cars. The effort, which will initially involve an investment by the government of $15,000,000 over a period of five years,[17] includes both the development of cars powered by lead-acid batteries and the development of high-temperature batteries for future use. Pictures and data on two cars constructed in the government-sponsored Japanese program are shown in Appendix B. These cars are powered by lead-acid batteries.

II. ADVANTAGES OF ELECTRIC AUTOMOBILES

Reduction in fuel consumption and air pollution would result from the use of electric instead of gasoline-powered cars, although electric automobiles must be economically competitive with other vehicles before such benefits can be realized. The effect on electric utilities of the introduction of electric cars must also be considered.

To determine the magnitude of these factors, it is necessary to estimate the rate of penetration of the automobile market by the electric car. For this purpose, it was assumed that the electric car would reach a production level of 100,000 units in 1985 and 5,000,000 units in the year 2000 (see Table I). This latter figure would represent 20 to 25% of the total market but of the total cars on the road by 2000, only 10% would be electric. This is the most rapid penetration of the market considered to be feasible because of the time required for development, preparation for production, and customer acceptance.

The electric cars were assumed to be small commuter cars weighing 2800 lb (1275 kg), including 300-lb load, and to replace gasoline-powered cars of similar capability that could travel 20 miles/gal of gasoline. Additional characteristics of the two types of automobiles are given in the subsections below.

A. Potential Savings in U.S. Petroleum Consumption

The development of economically competitive electric automobiles would reduce the demand for oil and, thus the need for oil imports. The introduction of electric cars by about 1985 and a gradual buildup to a total of 18,000,000 cars on the road by the year 2000 would result in a cumulative savings of petroleum of 1.3 billion barrels by replacement of gasoline cars driven 10,000 miles/year at 20 miles/gal (see Table I). The annual savings at that time would be about 270 million barrels of oil per year. Although

Table I. Projected Rate of Production of Electric Automobiles and Impact on U. S. Petroleum Consumption

	No. of Electric Cars			Petroleum Saved[a]	
	Produced	In Use	Cumulative Car-Years	Cumulative Barrels[b]	Value,[c] $Million
1982	1×10^4				
1985	1×10^5	2×10^5	3×10^5	4.5×10^6	27
1990	1.5×10^6	1.8×10^6	5.5×10^6	8.2×10^7	490
2000	5×10^6	1.8×10^7	8.5×10^7	1.3×10^9	7800

[a] Assumes electricity generated by means other than burning oil.

[b] Savings of 15 barrels of petroleum per year of gasoline-powered car operation, assuming 80% conversion of petroleum to gasoline (or product of equivalent value), and car utilization of 10,000 miles/yr at 20 miles/gal of gasoline.

[c] Average cost of petroleum, $6/barrel.

this is a small fraction of the projected crude oil requirement for transportation in the year 2000, this extent of savings could be important in reducing the need for oil imports.

B. Comparison of the Energy Utilization Efficiency of Electric and Gasoline-Powered Cars

One means of supplying fuel for cars is to produce gasoline from coal.[18] This approach may be economically feasible in the later 1980's and may contribute substantially to our supply of liquid fuel at that time. Electric cars and gasoline-powered cars could then derive energy from the same source: coal. It is of interest to determine which of these means of utilizing coal for transportation energy would have the highest overall efficiency. This comparison is made in Table II. Because of uncertainty in the efficiencies for each energy-conversion step, high and low estimates are given. As shown in the table, the electric car appears to have a definite advantage in efficiency over the gasoline-powered car. The averages of the overall estimates of efficiency (19.5% for the electric car and 9% for the gasoline car) indicate that the gasoline car would use more than twice as much fuel (coal) as the electric car. If the loss of efficiency on conversion of coal to synthetic crude oil is not included (*i.e.*, it is not considered necessary to supplement the petroleum supply by conversion of coal to synthetic crude oil), the gasoline car would require 20% more fuel (heating value) in the form of crude oil than the electric car requires in the form of coal (based on comparison of average estimates of overall efficiencies of 16.3% and 19.5 % respectively).

C. The Effect of the Introduction of Electric Automobiles on Electric Utilities

Because of the difficulties in licensing new electric generating facilities and providing the means of heat rejection, the addition of devices that add to the utility load may be undesirable. Fortunately, electric cars, although requiring electric energy, may not require significant additional generating capacity.

Table II. Comparison of the Energy Conversion Efficiency of an Electric Car with a Synthetic-Gasoline-Powered Car

	Energy Conversion Efficiency, %				
	Electric Car		Gasoline Car		
Energy Conversion Step	Low	High	Low	High	Reference
Generating Plant	30	40			18, p. 314
Electrical Transmission	90	95			18, p. 314
Battery					18, p. 314
Charge	85	95			
Discharge	75	85			
Electrical to Mechanical	75	85			1, p. 12
Coal to Synthetic Crude					18, p. 175
2 bbl/ton[a]			38		
4 bbl/ton[b]				72	
Syn. Crude to Gasoline			80	85	19
Internal Combustion Engine			15	25	20, p. 136
Transmission[c]			85	95	21, p. 14-82
Gear Reducer			92	97	22, p. 1409
Overall Efficiency	13	26	3.6	14	
Average Overall Efficiency	19.5		9.0		

[a] 13,000 Btu/lb.

[b] 14,000 Btu/lb.

[c] Based on manual transmission. Automatic transmission may be 5-10% less efficient.

The amount of electric energy required for the projected rate of market penetration for electric cars (Table I) is shown in Table III. Even though it is projected that 20-25% of the cars sold in the year 2000 would be electric cars, only about 10% of the cars on the road would be electric.

Table III. Electrical Energy Required to Recharge Electric Vehicles

		Electrical Energy, kW-hr/yr		
Year	No. of Electric Cars[a]	Total U. S. Production[b]	Required for Battery Recharge[c]	Percent of Total Used by Elec. Cars
1985	2×10^5	4.3×10^{12}	1.0×10^9	0.02
2000	1.8×10^7	1.0×10^{13}	9×10^{10}	0.9

[a] From Table I.

[b] Ref. 23.

[c] Based on 10,000 miles/(car)(yr), 0.5 kW-hr/mile charged to battery (70% W-hr efficiency).

These cars would require less than 1% of the total electric energy generated in 2000.[23] If all cars were electric by that time (not considered to be practical), and even if some were larger models drawing more power than the small urban cars considered in this study, no more than 15 to 20% of the electric energy generated in the year 2000 would be required for electric car recharging.

If the cars are recharged primarily at night, during the period of low power demand, the additional power generating capacity required for the 18 million electric cars projected for 2000 would be insignificant (<<1% of the U.S. generating capacity). This method of charging would tend to level the generating load by increasing the base load and, thus, reduce the need for energy storage capacity on the utility networks. Additional peaking equipment (*e.g.*, gas or oil turbines) to provide power for electric cars would probably not be needed.

D. Environmental Impact of Electric Automobiles

Electric cars themselves would be virtually nonpolluting, but the electric power plants providing the electric energy do cause pollution. Thus, with the use of electric cars, the pollution problem caused by gasoline-powered cars would be transferred from the street to the power plant, where it could be more readily controlled.

A study completed by Gordian Associates[24] compares the total emissions resulting from a gasoline-powered automobile economy with the total emission resulting from an economy based on electric-powered vehicles. The comparison was made for the year 1980 and employed the 1975 Federal pollutant-emission standards for both stationary and mobile sources. The total emissions for each system are given in Table IV.

The total emissions for the electric motor vehicle (EMV) system were then recalculated to account for the tall stacks* employed in the discharge of these emissions from coal-burning power plants. The equivalent ground-level emissions for the two systems are compared in Table V.

It is clear from an examination of the figures presented in Table V that significant decreases in air pollutants can be achieved through the use of electric motor vehicles for private transportation.

E. Cost Comparison of Electric and Gasoline Cars

Lower fuel costs would be an incentive for ownership of an electric car instead of a gasoline-powered car, as illustrated by Table VI. If electric cars are recharged at night during the period of low demand, a low cost rate might be granted by utilities. However, a satisfactory system for metering the energy and assuring that the power is drawn during the off-peak period might require additional study by the utilities before a special rate could be charged. Even for the residental rate of 2.35¢/kW-hr,

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*The use of diffusional models resulted in a decrease in concentration such that "equivalent ground level emissions" for the EMV systems were about 0.01 of the total emissions.

Table IV. Comparative Environmental Impact in 1980 of Gasoline-Powered Motor Vehicles (GMV) versus Electric-Powered Motor Vehicles (EMV)[24]

	1980 Pollutant Emissions	
	EMV	GMV
Total Particulates, tons	8.2×10^5	3.4×10^5
Respirable Particulates (<5 μm dia), tons	1.3×10^5	1.9×10^5
Benzo(a)pyrene Particulates, tons	0.53	11
Sulfur Dioxide, tons	5.8×10^6	1.7×10^6
Nitrogen Oxides, tons	2.9×10^6	4.5×10^6
Carbon Monoxide, tons	1.3×10^5	2.1×10^7
Hydrocarbons, tons	1.0×10^5	4.7×10^6
Carbon Dioxide, tons	1.1×10^9	1.5×10^9
TOTAL HEAT[a], Btu	2.1×10^{15}	1.9×10^{16}
Radiation	Added radiation <<5% of natural background for general population.	-----
Noise	-----	Significantly greater for GMV than for EMV.
Miscellaneous	5,000 tons of oil discharged into waterways, additional electrical lines needed for recharging EMV (aesthetic impact).	29,000 tons of oil discharged into waterways.

[a] Includes some heating of waterways; thermal discharge greater for EMV system than for GMV. By 1980, thermal discharges into waterways should be subject to controls. Heat rejected by the EMV is based on the use of electricity produced by a coal-fired plant and that rejected by the GMV is based on the use of gasoline obtained from petroleum.

the cost of electric energy is 67% of the cost of gasoline for powering a similar car. In these calculations, it was assumed that the gasoline-powered car would be small and of high efficiency (20 miles/per gallon) and, therefore, the annual cost savings for an electric car is only $58 if the cost of electric energy is 2.35¢/kW-hr. With a significant increase in the cost of gasoline above the assumed value of 35¢/gal (tax to consumer not included), the savings for use of the electric car would increase. A further cost comparison is shown in Fig. 1, where fuel costs per mile for the two types of vehicles are as given functions of fuel costs and automobile efficiency.

Table V. The Equivalent Ground Level Emissions of Air Pollutants in 1980 from Gasoline-Powered Motor Vehicles (GMV) and Electric-Powered Motor Vehicle (EMV) Transportation Systems[24]

	Ground-Level Emissions Per Year[a]			
	Tons per Total System		Pounds per Vehicle	
	EMV	GMV	EMV	GMV
Total Particulates	8.2×10^{3}	1.9×10^{5}	1.1×10^{-1}	2.7
Respirable Particulates	1.3×10^{3}	1.4×10^{5}	1.9×10^{-2}	1.9
Benzo(a)pyrene Particulates	5.3×10^{-3}	11	7×10^{-8}	1.6×10^{-4}
Sulfur Dioxide	5.8×10^{4}	6.1×10^{5}	8.1×10^{-1}	8.5
Nitrogen Oxides	2.9×10^{4}	3.9×10^{6}	4.1×10^{-1}	54
Carbon Monoxide	1.3×10^{3}	2.1×10^{7}	1.8×10^{-2}	300
Hydrocarbons	1.0×10^{5}	3.2×10^{6}	1.4×10^{-2}	45

[a] Based upon 1975 emission standards for both mobile and stationary sources and 140 million motor vehicles in operation in 1980.

Table VI. Potential Savings in Fuel Costs for an Electric Automobile

	Energy Cost		Savings per year for Electric Car[a]
	Per Mile	Per Year[a]	
Cost of Gasoline at 35¢/gal[b]	1.75¢[c]	\$175	-----
Cost of Electric Energy[d]			
Residential at 2.35¢/kW-hr	1.2¢[e]	\$117	\$58
Off-Peak Residential at 1.2¢/kW-hr	0.6¢[e]	\$60	\$115

[a] Based on 10,000 miles/yr.

[b] Tax to consumer not included.

[c] Based on 20 miles/gal.

[d] Electric power costs based on 1973 Commonwealth Edison Company rate structure. The residential rate is that to residences for energy use greater than 325 kW-hr per month; the off-peak rate is that now given to residential and commercial users for water heating.

[e] Based on 0.50 kW-hr/mile required for battery charging.

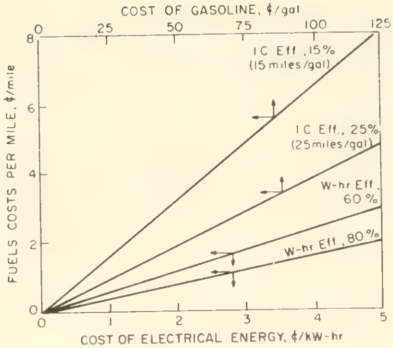

Fig. 1. Fuel Costs per Mile of Operation for Electric and Gasoline-Powered Automobiles as a Function of Fuel Costs and Automobile Efficiency.

Automobile Loaded Weight: 2800 lb
Energy Required at Wheels: 0.22 kW-hr/ton-mile
Urban Driving Profile I (Ref. 28, p. 77)
Electric Car Efficiency
  Electric to Mechanical: 82% (Ref. 1, p. 12)
Gasoline-Powered Car Efficiencies
  Gasoline Heating Value: 113,900 Btu gal (Ref. 21, p. 2-59)
  Transmission Eff.: 95% (Ref. 21, p. 14-82
  Gear Reducer Eff.: 97% (Ref. 22, p. 1409)

Fleet owners, who could certainly obtain the off-peak rate and, in some cases, attain a high annual mileage on each car*, would benefit even more from the use of electric cars. A potential penalty for the use of electric cars by fleet owners (and private owners as well) exists, however, in that the intial outlay (*i.e.*, capital costs) for the electric car can be expected to be higher than a gasoline car. Estimates in the literature of the additional cost for family automobiles range from \$150[2] to 25% of the cost of the gasoline car.[25] In spite of this potential capitalization penalty, the economic competitiveness of electric vehicles as delivery vans has been demonstrated in England and elsewhere. A cost study comparing battery-powered, gasoline-powered, and diesel-powered trucks showed that even with a \$2100-\$2300 premium paid for the electric truck, the total cost per mile was 44% higher for the diesel truck and 53% higher for the gasoline-powered truck than that for the electric truck.[26] Part of this advantage for the electric truck resulted from low maintenance costs. A study recently completed by the Marketing Section of Commonwealth Edison[27] showed that for its own fleet operation, a premium for an electric car of $2000 above the cost of a $2500 gasoline-powered car could be recovered over the lifetime of the electric car. The study assumed gasoline costs at the fleet rate and electric costs at the off-peak rate.

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*This mileage would require an electric car with a longer range than is now available. A car with a range of 100 miles, as is proposed above, could attain 20,000 to 25,000 miles per year in fleet service.

Accurate prediction of the cost of an electric vehicle is difficult at this time. However, it is apparent that even somewhat expensive electric cars or small trucks will find a niche in the transportation field if their performance is comparable to that of small gasoline-powered units and if they have satisfactory driving ranges (50 to 150 miles, depending on the application). Electric cars that meet the cost and performance goals that have been set for the ANL program (described in Section III) would certainly have an important role in the transportation field.

III. DESCRIPTION OF ANL PROGRAM

A. Development of ANL High-Energy Batteries

Several demanding applications for batteries have gone unfulfilled because of the limited performance capabilities and high cost of available batteries. To meet these needs, electrically rechargeable lithium/sulfur batteries are being developed at ANL for use as (1) energy storage devices for electric utilities and (2) power sources for electric automobiles. The installation of batteries on electric utility networks would permit the utilities to store energy generated at night by coal-burning or nuclear base-load plants and to discharge the batteries to the network during the day when demand is highest, thereby, reducing the need for gas or oil-burning turbine generators.[29] As discussed in Section II, electric automobiles could be recharged at night by electricity produced from coal, nuclear energy, or other energy sources. Thus, the successful development of batteries for either application would reduce our dependency on foreign sources of oil.

The development of the energy storage battery is funded by the U.S. Atomic Energy Commission (AEC). The development of the automobile battery was funded by the National Science Foundation (NSF) until January 31, 1974; the program is being continued under the sponsorship of the AEC. AEC support for development of the automobile battery began in November, 1973. The program for both applications involved the work of about 30 scientific personnel in FY1974 and was increased to an effort of 50 personnel in FY1975 (starting July 1, 1974). The history of the ANL program is described in Appendix C.

The tentative performance goals that we have set for batteries suitable for use in off-peak energy storage and electric cars are shown in Table VII. In general, the electric automobile battery has more stringent specific-energy and specific-power requirements than the off-peak energy battery. The specific energy goal for the off-peak energy application is not a direct requirement, but results from consideration of the goal for cost of capacity and an estimate of the projected cost per unit weight that can be

Table VII. Performance Goals for Lithium/Sulfur Batteries

Goal	Battery Application	
	Electric Car	Off-Peak Energy Storage
Battery Capacity	35 kW-hr[a]	10 MW, 40-60 MW-hr
Cost of Capacity	\$20-25/kW-hr	\$15-25/kW-hr
Specific Energy	150 W-hr/kg	120-150 W-hr/kg
Specific Power		
Peak (15 sec)	200 W/kg	---------
Sustained Discharge	70 W/kg	40 W/kg
Discharge Period	2-4 hr	4-14 hr
Charge Period	1-6 hr	4-8 hr
Watt-Hour Efficiency	50-70%	70%
Cycle Life	1000	1500

[a] Sufficient for a 100-mile range for a 1250-kg car.

expected for these batteries. The goals in Table VII are now being reviewed. The duty cycle for the off-peak energy application will be determined by a simulation study in cooperation with several electric utilities. The electric car goals are also being reconsidered.

Lithium and sulfur are attractive electrode materials for an electric car battery because they have low equivalent weights and form a cell with a high voltage of about 2.3 V. High current densities (>1 A/cm^2) can be obtained for lithium/sulfur cells having a molten-salt electrolyte of LiCl-KCl eutectic (mp, 352°C). The use of this salt requires operation of the cell at about 400°C. On the basis of these characteristics, calculations show that compact cells with negative electrodes of molten lithium and positive electrodes of molten sulfur would have a high specific energy (>300 W-hr/kg) and a high specific power (>300 W/kg). However, in our work to date, materials problems and loss of sulfur from the positive electrode have limited the life of such cells to less than 100 cycles and prevented the development of compact cells.

Studies[30,31] have indicated that the problems related to the use of elemental sulfur and lithium can be avoided by the use of lithium and sulfur compounds as electrode materials. Cells having such electrodes show promise of meeting the goals of Table VII. The use of solid Li-Al instead of molten lithium in negative electrodes reduces attack on the ceramic separators and insulators by reducing the lithium activity. With these electrodes, separators of boron nitride fabric have performed without failure for more than 1000 hr. However, because of the higher specific energy that is theoretically attainable for cells having molten lithium electrodes, work on these electrodes is continuing. It has also been demonstrated that sulfur loss from the sulfur electrode can be reduced by the addition of arsenic; however, even more promosing results have been obtained with the use of positive electrodes of FeS_2 and FeS. Long cycle life (>100 cycles) at high sulfur utilization (60 to 80% of theoretical) have been attained with FeS_2 electrodes. Studies with FeS electrodes, which were begun only recently, are also promising in these respects.

As a result of these developments, tests of full-scale cells, hermetically sealed by welding, have been undertaken. The general design of these cells is illustrated in Fig. 2. As information is gained in these cell tests, appropriate changes are made in electrode, configurations, cell components, etc. In a recent test, a welded cell with an FeS_2 positive electrode and Li-Al negative electrodes achieved a maximum specific energy of 155 W-hr/kg; the typical specific energies during the operating period of 2137 hr (111 cycles) were 110-135 W-hr/kg.[32] It is expected that similar cells might achieve a specific energy of 175 W-hr/kg by the use of more compact electrodes having better geometry control and by reduction of the amount of electrolyte. The development of such cells would permit the construction of a battery that meets the specific energy goals of Table VII, namely, 150 W-hr/kg; in calculating specific energy, the weights of associated components such as insulation and electric connectors are included in the battery weight.

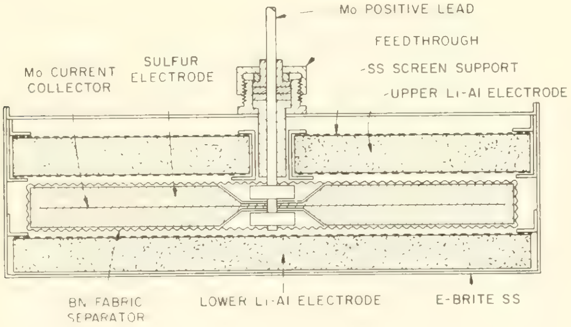

Fig. 2. Schematic Diagram of Full-Scale Lithium/Sulfur Cell.

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Long cycle life and low cost are the most important and the most difficult goals for the batteries. Improvements in dimensional stability of the electrodes and identification of corrosion-resistant cell components are expected to contribute significantly to the attainment of longer cell lifetimes. Work now under way shows promise of solving these problems. To reduce the cost of cells, less expensive separator and insulator materials are being evaluated. Moreover, recent studies of cells having FeS positive electrodes have shown that iron may be a suitable material in the positive current collector (in cells with FeS_2 electrodes, only molybdenum current collectors have shown adequate corrosion resistance).

B. Transfer of Technology to Industry

Plans are being formulated to transfer to industry the knowledge and technology gained at ANL in the battery development program. As soon as cells have been designed and operated that approach the specific energy and power goals for several hundred cycles, development and testing of batteries will begin. Batteries of ten or more cells will be constructed by a commercial vendor to ANL specifications as one means of transfeering the technical information to industry. Also, several engineers and chemists employed by firms having battery manufacturing or development capabilities are participating in the ANL program for periods of about one year. Not only will these industrial participants provide experience to the program but their participation will assist battery manufacturing firms in gaining sufficient knowledge of the ANL batteries to bid on construction of cells and batteries.

As a result of these efforts, it is expected that by 1980, our electric car battery that meets the goals set by the program will be installed in a vehicle for testing by an outside organization.

APPENDIX A

BATTERY DEVELOPMENT IN INDUSTRY

A summary of research and development programs on different types of batteries at various laboratories is presented in Table VIII. In the development of the lithium/sulfur battery, the largest effort is at Argonne, followed by those at General Motors Corp. and Atomics International. All three of these laboratories have recently turned their attention toward cells employing a metal sulfide (*e.g.*, FeS_2, FeS, Cu_2S) as the active material in the positive electrode. The Argonne effort is not only larger, but it is broader in scope and has progressed further into the hardware stage than the other two programs. Full-scale (5-in dia) hermetically sealed cells are now being tested in this program. The General Motors program is directed toward the electric automobile application, whereas the Atomics International effort is concerned with off-peak energy storage. The Argonne program involves both applications. Development work on lithium/sulfur batteries is also in progress in the U.S.S.R. and Czechoslovakia, but no detailed information is available on the status of the programs and its intended application.

As indicated in Table VIII, at least twelve organizations are investigating sodium/sulfur batteries. All of these organizations except Dow Chemical are using beta alumina, an ionically conductive solid ceramic material, as the electrolyte. (The Dow Chemical cell uses very fine glass fibers as a solid electrolyte.) The technology of the sodium/sulfur cells has advanced to the point that batteries are being assembled for prototype demonstration tests. One persistent problem, which has not yet been solved successfully, is that upon extended charge-discharge cycling the beta-alumina electrolyte develops cracks that limit the cell lifetime. There is also a question as to whether the beta-alumina tubes can be fabricated at a sufficiently low cost for commercial application. The Dow Chemical cell is at an earlier stage of development, and a difficult practical problem has been encountered in sealing the glass electrolyte fibers to a plenum containing the liquid sodium.

A significant development effort by the Udylite Company is in progress on zinc/chlorine batteries. In these batteries, the chlorine is stored as the hydrate ($Cl_2 \cdot 8H_2O$), which is stable up to 28.7°C at 5 atm chlorine pressure; thus, a refrigeration system must be provided to handle the chlorine that is generated when the battery is charged. Because much of the information on the Udylite battery is proprietary, an evaluation of the prospects of its success in commercial application is difficult to make. However, Udylite has demonstrated a primary (nonrechargeable) zinc/chloride battery in an electric vehicle.

The lithium/chlorine battery is being investigated at SOHIO, General Motors, Oak Ridge National Laboratory and Westinghouse. The cells have a positive electrode of liquid lithium and an electrolyte of molten LiCl, which requires operation at high temperatures ($\sim$600°C). In the SOHIO version, the chlorine is stored as $TeCl_4$ in a graphite matrix. In the other cells, it is collected as gaseous chlorine; this presents a difficult storage problem when the cell is charged. Although this difficulty is avoided in the

Table VIII. Battery Research and Development Programs

Type of Cell	Organization	Estimated Level of Effort[a] (Staff Level)	Goals[a]
Lithium/Sulfur	Argonne Natl. Laboratory	45	U,T
	Atomics International	4	U
	General Motors Corp.	5-10	T
	Institute of Power Sources (Moscow)	NA	NA
	Electrical Engineering Laboratory (Prague)	NA	NA
Sodium/Sulfur	Ford Motor Company	13	U,T
	TRW, Inc.	5	U
	General Electric Corp.	5	U,T
	Dow Chemical Co.	5	
	ESB, Inc.	NA	U
	British Railways Board, UK	12	T
	Electricity Council Research	15	U,T
	Compagnie GE, France	12	U,T
	Toshiba - Yuasa, Japan	30	U,T
	Japan Storage	NA	U,T
	Toyota Automobiles	NA	T
	Brown - Boveri (Switzerland)	NA	U
Zinc/Chlorine	Udylite Co.	35	U,T
Lithium/Chlorine	SOHIO	NA	T
	General Motors Corp.	NA	T
	Oak Ridge Natl. Laboratory	1	E
	Westinghouse Corp.	NA	E
Aluminum/Chlorine	ESB, Inc.	NA	U
Advanced Lead/Acid	Gould, Inc.	NA	T
	Japan Storage	NA	T
	Yuasa Battery Co.	NA	T
	ESB, Inc.	NA	T
Lithium/Organic	Electrochimica Corporation	NA	E
	Globe Union Corporation	NA	E
	Union Carbide, Ohio	NA	E
	Tyco Laboratory, Inc.	NA	E
	SAFT, France	NA	E
	Matsushita	NA	E
Zinc/Air	All major battery companies listed above	Variable	T

[a] U = Utility applications
T = Transportation uses
E = Exploratory
NA = Not available

SOHIO cell, the use of the graphite-$TeCl_4$ combination results in a low specific energy. The most serious problems with the lithium/chlorine cells are corrosion of the cell materials and the handling of chlorine. Much of the information concerning lithium/chlorine cell is proprietary, but it appears that little, if any, work has been done on practical hardware development for cells and batteries. Although very high power densities (40 W/cm^2) have been obtained in short-term tests of lithium/chlorine cells, there is some question concerning their rechargeability with extended cycling.

Aluminum/chlorine cells were investigated previously at Tyco Laboratory and are now being developed at ESB, Inc. Little information appears to be available on the program. These cells have an $AlCl_3$-based electrolyte and operate at ∿150°C and a chlorine pressure of several atmospheres. Aluminum/chlorine batteries, if developed successfully, probably will have relatively low power densities; in this case, they would be better suited to off-peak energy storage than to electric automobiles.

Several organizations are conducting research and development programs to improve the performance of lead-acid batteries, particularly specific energy. Although lead-acid batteries are used now in various vehicles (delivery trucks, fork-lifts, rail coaches), their high cost per unit of storage capacity and moderate performance per unit weight are inherent limitations because of the high equivalent weight of lead. There appears to be little doubt that one of the higher-performance systems listed in Table VIII will eventually have significant technical and economic advantages over lead-acid batteries, both for electric vehicles and for off-peak energy storage.

A variety of cells employing lithium as the negative electrode material and an organic electrolyte are under study. The electrolyte consists of an organic solvent such as dimethylsulfoxide and an inorganic solute such as LiCl or $LiClO_4$, which provides some lithium-ion conductivity. Thus far, these cells are not electrically rechargeable and are capable of only low power densities. For these reasons, they cannot be considered seriously at the present time either for electric automobile batteries or for off-peak energy storage.

Various battery companies are investigating the zinc/air system for different applications. The cells use zinc as the negative electrode, air as the positive electrode reactant, and aqueous KOH solution as the electrolyte. Although such batteries have been developed to the stage of practical application, they are recharged mechanically, *i.e.*, by adding zinc plates and new electrolyte. The electrolyte becomes exhausted through the absorption of CO_2 in the air by KOH electrolyte. It is possible that electrical recharging of zinc/air batteries may be possible with further development efforts, but no such battery has been reported to date. Again, however, this effort is proprietary, and information on developments that may be in progress is not available.

APPENDIX B

JAPANESE ELECTRIC VEHICLES

PASSENGER CAR

Dimensions

Overall Length:	3,165 mm	(125 in.)
Overall Width:	1,420 mm	(56 in.)
Overall Height:	1,315 mm	(52 in.)
Curb Weight:	912 kg	(2,013 ib)
Laden Weight:	1,132 kg	(2,500 lb)
Passengers:	4	

Motors

DC Series
2 x 5.6 kW
2 x 45 V
Thyristor Chopper Control

Batteries

Lead-Acid
220 Ah at 5 hr rate
96 V
4 units

Performance

Maximum Speed:	48 mph
Range (at 24 mph):	80 miles
Acceleration (to 18 mph):	4 sec
Climbing (6^{0}):	24 mph

Car Maker: Daihatsu Kogyo Co.

COMPACT PASSENGER CAR

Dimensions

Overall Length: 3,350 mm (132 in.)
Overall Width: 1,580 mm (62 in.)
Overall Height: 1,540 mm (61 in.)
Curb Weight: 1,385 kg (3,057 lb)
Laden Weight: 1,660 kg (3,665 lb)
Passengers: 5

Motors

DC Series
20 kW
192 V
Thyristor Chopper Control

Batteries

Lead-Acid
158.5 Ah at 5 hr rate
192 V
16 units

Performance

Maximum Speed: 48 mph
Range (at 24 mph): 100 miles
Acceleration (to 18 mph): 3 sec
Climbing (6^0): 24 mph

Car Maker: Toyota Motors Co.

APPENDIX C

HISTORY OF THE ANL BATTERY PROGRAM

The high-energy batteries that are currently under development at ANL employ liquid lithium or a solid lithium-aluminum alloy as the negative electrode, and a molten alkali-halide salt mixture as the electrolyte. The basic and applied chemistry and the engineering technology of liquid-metal and molten-salt systems have been under investigation for many years in the Chemical Engineering Division of ANL in connection with various research and development programs, including studies of nuclear fuel processing, liquid-metal coolants for fast breeder reactors, regenerative galvanic cells, and, more recently, high-temperature secondary batteries. Investigations of electrochemical cells having alkali-metal electrodes and molten-salt electrolytes began in 1961 in a program to develop thermally regenerative galvanic cells for the direct conversion of heat to electricity. This work led to the invention of secondary lithium/chalcogen cells at ANL about six years ago. The research and development efforts on lithium/chalcogen cells since that time have resulted in over 100 publications and a number of patents, and have led to the present development of cells employing a lithium/aluminum alloy as the negative electrode, iron sulfide as the positive electrode, and LiCl-KCl eutectic as the molten-salt electrolyte.

The original work on lithium/chalcogen cells was funded by the AEC Division of Research. Subsequent program directed toward various specific applications have been supported at different times by the U.S. Army Mobility Equipment Research and Development Center, the Environmental Protection Agency's Office of Air Programs, the National Heart and Lung Institute of the Department of Health, Education, and Welfare, the National Science Foundation (RANN Program), and the AEC Division of Applied Technology.

REFERENCES

1. 1972 Automobile Facts and Figures, p. 35, Motor Vehicle Manufacturers Association of the U.S., Inc. (1972).

2. J. H. B. George, L. J. Stratton, and R. G. Acton, "Prospects for Electric Vehicles. A Study of Low-Pollution-Potential Vehicles-Electric," Report to the Department of Health, Education, and Welfare by Arthur D. Little, Inc. (May 15, 1968).

3. E. J. Cairns and R. K. Steunenberg, "High-Temperature Batteries," in Progress in High Temperature Physics and Chemistry, Vol. 5, p. 65, C. A. Rause, Ed., Pergamon Press, New York (1973).

4. R. K. Steunenberg, R. D. Pierce and L. Burris, "Pyrometallurgical and Pyrochemical Fuel Processing Methods," Progress in Nuclear Energy, Series III, Process Chemistry, p. 461, C. E. Stevenson, A. T. Gresky and E. A. Mason, Eds., Pergamon Press, New York (1970).

5. Sodium Technology Quarterly Report, April-June 1972, USAEC Report ANL-7957, Argonne National Laboratory (1972).

6. Sodium Technology Quarterly Report, July-September 1972, USAEC Report ANL-7974, Argonne National Laboratory (1973).

7. Sodium Technology Final Report, April 1973, USAEC Report ANL-7997, Argonne National Laboratory (1973).

8. E. J. Cairns *et al.*, Galvanic Cells with Fused-Salt Electrolytes, USAEC Report ANL-7316 (November 1967).

9. E. J. Cairns and H. Shimotake, Science 164, 1347 (1969).

10. H. Shimotake *et al.*, "Lithium/Sulfur Cells and Their Potential for Vehicle Propulsion," Proc. 1st Internat. Electric Vehicle Symp., Phoenix, Ariz., Nov. 5-7, 1969, p. 392. Electric Vehicle Council, New York (1970).

11. H. Shimotake, A. K. Fischer, and E. J. Cairns, "Secondary Cells with Lithium Anodes and Paste Electrolytes," Proc. 4th IECEC, p. 538, AIChE, New York (1969).

12. E. C. Gay *et al.*, "Lithium/Chalcogen Secondary Cells for Components in Electric Vehicular-Propulsion Generating Systems," USAEC Report ANL-7863 (1972).

13. M. L. Kyle *et al.*, "Lithium/Sulfur Batteries for Electric Vehicle Propulsion," Proc. 1971 IECEC, p. 80, SAE, New York (1971).

14. H. Shimotake *et al.*, "The Development of Lithium/Selenium Secondary Cells and Batteries for Implantation," Proc. 1970 IECEC, Vol. I, p. 3, ANS, Hinsdale, Ill. (1972).

15. E. C. Gay *et al.*, "Secondary Cells Using Lithium Anodes and Sulfur-Selenium-Thallium Cathodes," Proc. 1972 IECEC, p. 54, ACS, Washington (1972).

16. E. J. Cairns *et al.*, Development of High-Specific-Energy Batteries for Electric Vehicles, Progress Report for the Period August 1972-January 1973, USAEC Report ANL-7998, Argonne National Laboratory (1973).

17. "Development Program of Electric Car in Japan," Japanese Ministry of International Trade and Industry (April 1971).

18. H. C. Hottel and J. B. Howard, New Energy Technology, Some Facts and Assessments, MIT Press, Cambridge (1971).

19. A. A. Jonke, Argonne National Laboratory, private communication (1973).

20. A. L. Hammond, W. D. Metz and T. H. Maugh, Energy and the Future, AAAS, Washington (1973).

21. J. K. Salisbury, Ed., Kent's Mechanical Engineers' Handbook 12th Edition, Vol 23, John Wiley & Sons, Inc., New York (1950).

22. L. S. Marks, Mechanical Engineers' Handbook, 5th Edition, McGraw-Hill Book Co., New York (1951).

23. Electric Utility Industry R & D Goals Through the Year 2000, Electric Research Council Publication No. 1-71, Appendix F (1971).

24. S. K. Mencher and N. M. Ellis, "The Comparative Environmental Impact in 1980 of Gasoline-Powered Motor Vehicles versus Electric-Powered Vehicles. A summary of Results," in Proc. 2nd Internat. Electric Vehicle Symp., Atlantic City, N. J., November 8-10, 1971, p. 755, Electric Vehicle Council, New York (1972).

25. G. A. Hoffman, "Systems Design of Electric Automobiles" in Transportation Research, Vol I, p. 3, Pergamon Press (1967).

26. M. A. Hind, Electric Vehicles for Industry, p. 12 (June 1973).

27. W. Shafer, Marketing Section Engineer, Commonwealth Edison Co., private communication (Dec. 7, 1973).

28. E. J. Cairns *et al.*, Development of High-Energy Batteries for Electric Vehicles, Progress Report for the Period July 1970-June 1971, USAEC Report ANL-7888, Argonne National Laboratory (1971).

29. M. L. Kyle, E. J. Cairns, and D. S. Webster, Lithium/Sulfur Batteries for Off-Peak Energy Storage: A Preliminary Comparison of Energy Storage and Peak Power Generation Systems, USAEC Report ANL-7958, Argonne National Laboratory (1973).

30. P. A. Nelson *et al.*, High-Performance Batteries for Off-Peak Energy Storage. Progress Report for the Period July-December 1973, USAEC Report ANL-8057, Argonne National Laboratory (in press).

31. P. A. Nelson *et al.*, Development of High-Specific Energy Batteries for Electric Vehicles, Progress Report for the Period August 1973-January 1974, USAEC Report ANL-8058, Argonne National Laboratory (1974).

32. P. A. Nelson *et al.*, High Performance Batteries for Off-Peak Energy Storage and Electric Vehicle Propulsion, Progress Report for the Period January-June 1974, USAEC Report ANL-8109 (in preparation).

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IMPACT OF FUTURE USE OF ELECTRIC CARS IN THE LOS ANGELES REGION: VOLUME I - EXECUTIVE SUMMARY AND TECHNICAL REPORT

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
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Ann Arbor, Michigan 48105

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Office of Air and Waste Management
Office of Mobile Source Air Pollution Control Programs
Alternative Automotive Power Systems Development Division
Ann Arbor, Michigan 48105

October 1974

This report is issued by the Environmental Protection Agency to report technical data of interest to a limited number of readers. Copies are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations as supplies permit from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711; or, for a fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

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ABSTRACT

Impacts of the use of electric cars in the Los Angeles region in 1980-2000 were projected for four-passenger subcompact electric cars using lead-acid and advanced batteries, with urban driving ranges of about 55 and 140 miles, respectively. Data from Los Angeles travel surveys shows that such cars could replace 17 to 74 percent of future Los Angeles autos with little sacrifice of urban driving. Adequate raw materials and nighttime recharging power should be available for such use in the Los Angeles region. Air quality improvements due to the electric cars would be minor because conventional automobile emissions are being drastically reduced. The electric cars would save little energy overall, as compared to conventional subcompacts, but would save a considerable amount of petroleum if they were recharged from the nuclear power plants that are planned.
The electric subcompacts would be 20-60% more expensive overall than conventional subcompacts until battery development significantly reduces battery depreciation costs.

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INTRODUCTION

This report is published in three volumes:

Volume 1, Executive Summary and Technical Report

Volume 2, Task Reports on Electric Car Characteristics and Baseline Projections

Volume 3, Task Reports on Impact and Usage Analyses

Volume 1 is a comprehensive account of the effects that electric cars would have on the air quality, energy use, and economy of the Los Angeles region in 1980-2000. Volumes 2 and 3 contain ten individual reports documenting the analyses on which Volume 1 is based. These reports detail the methods, data, assumptions, calculations, and results of the study tasks, and were originally published at the conclusion of each task.

Task reports in Volume 2 project future characteristics of electric cars and of the Los Angeles region in which they would be used, as follows:

1. D. Friedman and J. Andon (Minicars, Inc.) and W. F. Hamilton, Characterization of Battery-Electric Cars for 1980-2000

   Postulates electric vehicle performance requirements, projects representative future battery characteristics, calculates urban driving range versus total car weight, and estimates energy and material requirements for selected driving ranges.

2. G. M. Houser, Population Projections for the Los Angeles Region, 1980-2000

   Projects population of California's South Coast Air Basin, which includes greater Los Angeles, by county and age group.

3. W. F. Hamilton and G. M. Houser, Transportation Projections for the Los Angeles Region, 1980-2000

   Projects Los Angeles freeway and transit networks, auto population, auto usage, auto size and age distributions, and average fuel consumption.

4. J. Eisenhut, Economic Projections for the Los Angeles Region, 1980-2000

   Projects employment and income for the South Coast Air Basin, and the payroll and employment of businesses involved in production, distribution, and maintenance of automobiles and parts.

5. A. R. Sjovold, Electric Energy Projections for the Los Angeles Region, 1980-2000

   Summarizes the US energy situation as forecast in recent studies, and in this context projects electric energy production and consumption in the South Coast Air Basin, noting energy available for electric car recharging and its basic sources.

Task reports in Volume 3 project impacts due to various levels of electric car use and investigate possible future levels of use, as follows:

6. J. R. Martinez and R. A. Nordsieck, An Approach to the Analysis of the Air Quality Impact of Electric Vehicles

   Selects the "DIFKIN" computer model and linear rollback as means for analyzing future air quality in the South Coast Air Basin, designates important cases for investigation, and details required methodology.

7. J. R. Martinez and R. A. Nordsieck, Air Quality Impacts of Electric Cars in Los Angeles

   Forecasts stationary and vehicular pollutant emissions in spatial and temporal detail, with and without electric cars, and calculates consequent air quality levels relative to Federal standards.

8. A. R. Sjovold, Parametric Energy, Resource, and Noise Impacts of Electric Cars in Los Angeles

   As a function of percentage electric car use, forecasts total energy consumption and petroleum consumption in the South Coast Air Basin through the year 2000; compares annual consumption and rolling inventory of key electric car materials with past and projected US production, consumption, and reserves; analyzes possible reductions of community noise from electric car use.

9. J. C. Eisenhut, J. A. Cattani, and F. J. Markovich, Parametric Economic Impacts of Electric Cars in Los Angeles

Projects life cycle costs of alternative electric cars in comparison with conventional cars; analyzes and projects changes in employment and payroll in industry segments impacted by electric cars, including service stations, battery manufacturing, auto parts and repairs, and auto sales; considers overall regional and national economic impacts of electric cars.

10. W. F. Hamilton, Usage of Electric Cars in the Los Angeles Region, 1980–2000

Analyzes 1967 data to determine distributions of daily driving range in Los Angeles and the applicability of limited-range electric cars; reviews market trends and estimates the potential free-market sales of electric cars in the South Coast Air Basin; hypothesizes particular levels of electric car use for impact evaluations; and considers relative economic incentives likely to be required to obtain these usages.

1 EXECUTIVE SUMMARY

The scope of this study was limited to battery-electric cars in the years 1980-2000. The study's focus was on California's South Coast Air Basin, an area of some 10,000 square miles (25,000 square kilometers) bounded by mountains and ocean; this area includes greater Los Angeles and had 1970 populations of 10 million people and over 5 million cars. The study's emphasis was on environmental, energy, and socioeconomic impacts of electric car use rather than on vehicle technology and design.

As a starting point for impact calculation, future electric cars were briefly characterized. Four representative battery technologies were considered, with the basic capabilities shown in Fig. 1.1. Lead-acid battery characteristics were projected from those of high-performance electric vehicle batteries which have already been tested in electric cars. Characteristics of advanced batteries were taken from achievements and goals of development programs at Gould, Inc., Energy Development Associates, Inc., and Argonne National Laboratory.

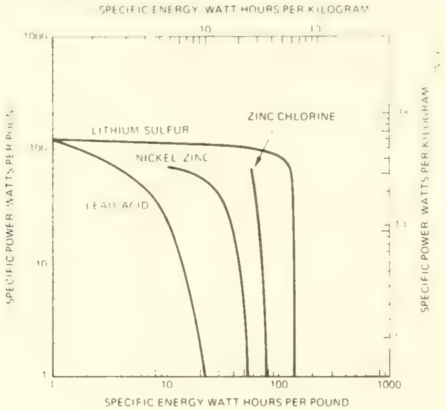

Figure 1.1. Assumed Battery Capabilities

A computer program was developed to model battery discharge according to Fig. 1.1 while meeting power requirements of electric cars for urban driving. The SAE Metropolitan Area Driving Cycle for electric cars was used in this program; it calls for a stop each mile (1.6 km), an average speed of 24 mph (39 km/hr), and an energy requirement per mile very near that of the US Federal driving cycle used in official measurement of auto exhaust emissions and fuel economy.

After a parametric analysis, the specific car ranges of Table 1.1 were selected for the impact analysis. The electric cars were efficient four-passenger subcompacts with performance slightly below that of current low-performance conventional subcompacts; they were capable of accelerating from 0 to 40 mph (65 km/hr) in 10 seconds, and of cruising on a freeway at 60 mph (100 km/hr). At a constant 30 mph on a level road, car ranges would be over twice those shown for urban driving; in hilly terrain or near the end of battery life, however, they could be significantly less than in Table 1.1.

TABLE 1.1

CHARACTERISTICS OF ELECTRIC CARS

(For Urban Use)

Availability, Year	1978	1980	1985	1990
Battery Type	lead-acid	nickel-zinc	zinc-chlorine	lithium-sulfur
Test Weight, lb (with 450 lb payload)	3,975	3,530	2,950	2,655
kg	1,803	1,602	1,338	1,204
Urban Driving Range, mi	54	144	145	139
km	87	232	233	224
Recharge Energy Requirement, kW·hr/mi	0.79	0.51	0.41	0.45
kW·hr/km	0.49	0.32	0.25	0.28
Cost (less battery), 1973 dollars	2,977	2,945	2,891	2,795

Characteristics of batteries used in the electric cars are shown in Table 1.2. The lifetimes shown assume urban driving of about 30 mi/day (48 km/day). For the lead-acid battery, the projected range of lifetimes is based on current experience; the longer life projection is optimistic. For the nickel-zinc and zinc-chlorine batteries, the indicated lifetimes assume that developers' goals for lifetimes of 400 and 500 deep discharges, respectively, will be achieved, and that life with partial discharges will be increased in inverse proportion to discharge depth. For the lithium-sulfur battery, which must be maintained at a very high temperature, the indicated lifetime range is assumed to be independent of use. Cost and life characteristics for the zinc-chlorine and lithium-sulfur batteries are relatively uncertain, and the figures in Table 1.2 are quite optimistic.

The electric car ranges of Table 1.1 were selected after a new analysis of Los Angeles travel data which had been collected in an extensive 1967 survey. Figure 1.2 shows the resultant distribution of driving distances on the survey day for drivers with cars exclusively available to them. Most present Los Angeles drivers and virtually all future Los Angeles drivers fall in this category. The distribution of Fig. 1.2 was

---

TABLE 1.2

CHARACTERISTICS OF ELECTRIC CAR BATTERIES

(For Urban Car Use)

Battery Type	lead-acid	nickel-zinc	zinc-chlorine	lithium-sulfur
Weight, lb	1,500	1,090	570	300
kg	681	495	259	136
Energy Density, W·hr/lb	13	44	70	126
W·hr/kg	27.8	96	157	276
Energy Efficiency, Percent	46	66	70	62
Life, Years	1.3-3.4	5.8	7.3	3-5
Cost, 1973 Dollars	1,200	2,930	600	600

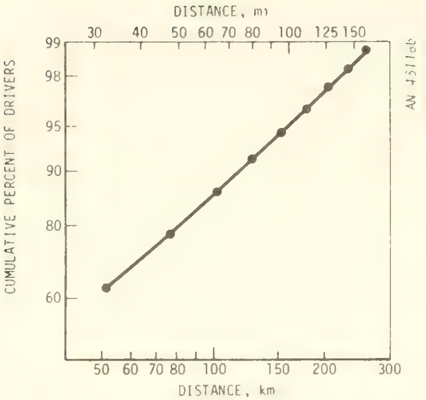

Figure 1.2. Distribution of Daily Driver Travel in the Los Angeles Area

derived from about 130,000 separate trips made by 30,000 drivers at 22,000 representative households. It shows that cars of Table 1.2 with 145-mile (230-km) range would be inadequate on only 2% of urban driving days. The car with 54-mile (87-km) range, however, would be inadequate on about 1 driving day out of 6, a frequency considered unacceptable. As a secondary car in a two-car household, however, where longer trips were accomplished by the primary car, even this car could be adequate on over 97% of driving days. Average daily car travel in Los Angeles is no greater than the national average, which has been growing quite slowly since the 1930s, and little future change is expected. The average in Fig. 1.2, 28.5 mi (45 km), is projected to increase only 6% by the year 2000.

Simple overnight recharging, rather than a system of battery exchange and recharge stations, was assumed. Overnight recharging would be easiest arranged at single-family houses with off-street parking. There will be about one million such households in Los Angeles in 1980 having at least one secondary car. Thus, as shown in Table 1.3, the shorter-range electric car would be applicable to the functions of one million cars in 1980, or 17% of all cars in the Air Basin; but these secondary cars would be driven less than the average car and would account for a smaller proportion of area travel. The longer-range electric cars could generally replace automobiles where overnight recharge facilities will be available. In 1990, 3.1 million automobiles in the Air Basin are expected to be parked off-street at single-family houses, where recharging would be most easily arranged. In 2000, recharge facilities might be available at all of the 5.6 million off-street parking places projected at Los Angeles residences. These are the bases for the corresponding applicability projections in Table 1.3.

Provision of certain battery materials for the numbers of cars indicated in Table 1.3 could perturb US metals markets. The nickel required for extensive regional use of nickel-zinc battery cars would require significant increases in US nickel imports. The lithium for wide use of lithium-sulfur batteries would require a major expansion in US production facilities, but this is not a serious problem: US reserves are adequate, and current production is modest.

TABLE 1.3

APPLICABILITY OF ELECTRIC CARS IN THE SOUTH COAST AIR BASIN

	1980	1990	2000
Cars, millions	1.0	3.1	5.6
Percent of all area cars	17	46	74
Daily travel, millions of mi	18	90	169
millions of km	29	145	272
Percent of all auto travel	11	46	74

Sources of recharge energy for electric cars were investigated through projection of future electric power production and consumption in the Los Angeles area. The result, which is subject to major uncertainties, is shown in Fig. 1.3. The peak demand is anticipated on hot August afternoons, but even on the peak day, demand is expected to fall dramatically in the late evening hours in the absence of car battery recharging. About 85 million kilowatt-hours, the shaded area in Fig. 1.3, would be available during the night of the peak 1990 day--more than enough to recharge the 3.1 million electric cars of Table 1.3.

Future peak power production is expected to grow at about 4-1/2% per year per capita in Los Angeles, and most of the new capacity is expected to be nuclear. Since the use of existing oil-fired plants in the Air Basin will be more expensive and cause air pollution, Fig. 1.3 assumes that oil-fired facilities will be used primarily for meeting peak loads,

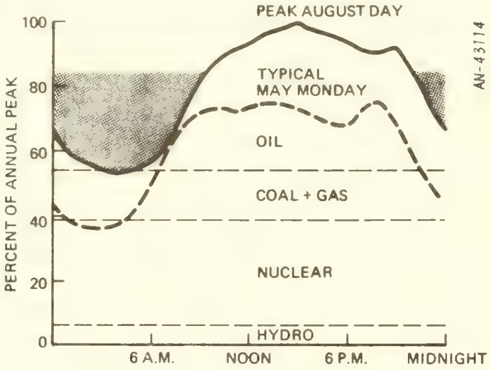

Figure 1.3. 1990 Electric Power Production and Consumption in the South Coast Air Basin

and so would be shut down in the late evening unless electric car recharging were in progress. On the peak day, petroleum would thus be the fuel for electric car travel. On low-demand days, however, such as the May Monday of Fig. 1.3, coal, gas, and nuclear fuel could provide recharge power. On an annual average basis, 46 percent usage of the efficient advanced-battery cars could enable a reduction in automotive petroleum usage of 28-35%, but only if nuclear power plants are built at the high rates planned by electric utilities serving the Los Angeles area.

The petroleum fuel consumption of the electric cars of Table 3.1 and internal-combustion-engine (ICE) cars are shown in Fig. 1.4. The thermal efficiency of electric power generation is assumed to be 36% and the efficiency of electric power transmission to be 91%, in line with utility projections for the Los Angeles region. All recharge energy is assumed in this efficiency comparison to be provided by oil-fired facilities. As the dashed line of Fig. 1.4 indicates, the fuel consumption of

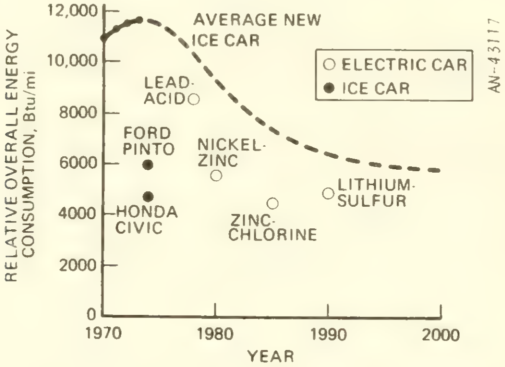

Figure 1.4. Auto Fuel Consumption

average ICE cars in Los Angeles is expected to improve by 50% in this century, in line with legislation now being considered by the Federal government. The improvement would be achieved partly through improved technology and partly through a substantial reduction in average car weight from its present level of 3,500 lb (1,600 kg). Fuel consumptions of ICE cars in Fig. 1.4 include a refinery energy penalty of 10%.

Despite the major improvement projected for the average ICE car, Fig. 1.4 shows that the electric cars promise further reductions in total energy consumption--as compared with the average ICE car. They offer little or no energy saving, however, as compared with existing ICE subcompacts of comparable size (and superior performance).

Electric cars can be nearly pollution-free. But as shown in Fig. 1.5, the 90% reductions of conventional auto exhaust emissions required by existing legislation in this decade will dramatically reduce total vehicular

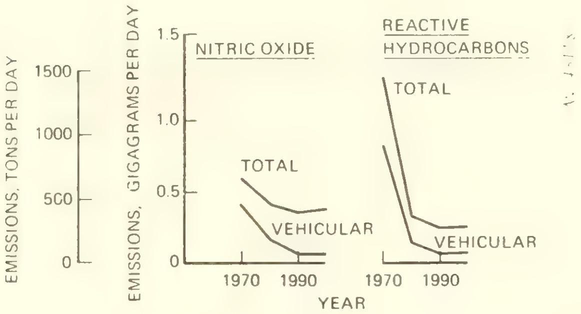

Figure 1.5. Projected Emissions of Air Pollutants Without Electric Car Use, South Coast Air Basin

emissions of air pollutants, and make cars a minor rather than major contributor to total projected emissions. Under these circumstances, air pollution will no longer be a critical problem in Los Angeles, and even extensive electric car use will have little further effect.

Table 1.4 shows worst-case air pollution projected for 1990 in relation to Federal air quality standards and 1970 measurements in Los Angeles. Concentrations of secondary pollutants (ozone and NO_2) were estimated by applying a photochemical-smog simulation to detailed forecasts of emissions. Concentrations of the other pollutants were assumed to decrease in direct proportion to the emissions. The 1990 baseline projection (no electric cars) in Table 1.4 shows major improvements in air quality, after which even very high usage of electric cars will reduce secondary pollutant concentrations relatively little, and will actually raise sulfur dioxide (SO_2) concentrations due to power plant emissions. The projected SO_2 levels assume only the use of low-sulfur fuel in power plants; if stack scrubbers were added, SO_2 levels with or without electric

TABLE 1.4

PROJECTED WORST-CASE AIR POLLUTION, SOUTH COAST AIR BASIN

Pollutant	Measure		US Standard	1970 Actual	1990 Baseline	1990 Change for 80% Electric Car Use
	Units	Period				
Ozone	pphm[*]	1 hr	8	62	15	-10%
NO_2	pphm	1 hr	--	43	10	-14%
CO	ppm[**]	1 hr	35	54	7	-26%
SO_2	pphm	1 yr	3.0	2.6	4.1	+14%
Particulates	$\mu g/m^3$	24 hr	260	357	437	-21%

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[*] Parts per hundred million.

[**] Parts per million.

[-] No hourly standard is established. The annual average concentration standard is 5 pphm; the 1970 actual annual average was 6.3 pphm.

cars would be well within Federal air quality standards. The impacts of electric cars shown in Table 1.4 would not be changed much by a two-year delay in imposing final auto emission standards or by relaxation of the nitrogen-oxides emission standard from 0.4 to 2 grams per mile.

The overall costs of electric car operation are projected in Table 1.5, together with costs of a conventional ICE subcompact automobile. The life of the conventional car is 100,000 mi (161,000 km) and 10 years; its initial cost is $2,270, its fuel economy is 30 mpg (0.078 liters per km), and it utilizes air pollution control devices with a significant initial and recurring cost. The electric cars are assumed to last for 12 years and 120,000 mi (193,000 km). Their higher initial costs (see Table 1.1)

TABLE 1.5

LIFE-CYCLE CAR COSTS

1973 cents per mile

	Conventional ICE Subcompact	Electric Cars			
		Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur
Depreciation					
Vehicle	2.3	2.5	2.5	2.4	2.3
Battery	0	3.5-9.2	5.1	0.8	1.2-2.0
Upkeep	2.4	1.5	1.2	1.2	1.2
Fuel	1.9	1.5	1.0	0.8	0.9
Pollution Control	0.9	0	0	0	0
Financing	1.6	2.5	3.7	2.2	2.2
Taxes, Insurance Parking, etc.	4.3	4.5	4.5	4.5	4.5
Total	13	16-22	18	12	12-13

are more than offset by longer life, lower maintenance, and reduced fuel costs. For the lead-acid and nickel-zinc battery cars, however, high battery depreciation costs make overall costs 22 to 66% higher than those of the conventional subcompact, or about equal to those of standard-size ICE cars. The much smaller depreciation costs projected for the zinc-chlorine and lithium-sulfur battery cars remain to be verified in practice.

The higher costs of the nearer-term electric cars would significantly reduce consumer income available for non-transportation expenditures. With 100% electric car use, 30,000-40,000 service station jobs would disappear, along with some 10,000-20,000 jobs in automobile service, parts, and sales businesses. The total job loss would be only partly compensated by increased employment in battery manufacturing. Overall, however, only about one percent of the regional labor force would be affected, over a period of years.

In conclusion, it appears that future electric cars could replace many Los Angeles automobiles with little sacrifice of urban mobility. Electric power facilities already planned for the Los Angeles region would be adequate for their nighttime recharge, and high levels of use in the Los Angeles region would pose problems of materials availability only in the case of nickel-zinc battery cars. Air quality improvements due to electric car use would be relatively minor in importance. Total energy saving would be modest, but potential reductions in regional automotive petroleum consumption are substantial, and could be the most important benefit of electric car use. Until battery depreciation costs are significantly reduced, electric car life-cycle costs would be high compared with ICE subcompacts.

CONCLUSIONS

1. Electric car range and performance can be adequate for substantial urban use. Even limited-range lead-acid battery cars could replace a million second cars in the Los Angeles area in 1980 (17% of all area cars) with little sacrifice in typical daily driving patterns. Electric cars utilizing advanced batteries such as nickel-zinc, zinc-chlorine, or lithium-sulfur batteries could have sufficient daily range for general urban use without serious travel restriction. Electric cars could perform the functions of 45-75% of Los Angeles cars in 1990-2000, depending on the fraction of off-street parking places equipped with electric outlets for overnight recharging.

2. Adequate electric power and material resources will be available for electric car use in Los Angeles. Available late-night capacity of electric utilities serving the Los Angeles region will be adequate for electric car recharge unless planned facilities are not constructed. No likely usage of lead-acid or zinc-chlorine battery cars in the Los Angeles region will significantly perturb US demand for key materials; demand for nickel and lithium, however, would be substantially increased by extensive regional use of nickel-zinc and lithium-sulfur battery cars.

3. Air quality benefits obtained by electric car use in the Los Angeles region are projected to be minor. By the time any significant level of electric car use could be obtained, the projected improvement in combustion-powered car emissions will have significantly reduced car emissions as a factor in overall regional air pollution. The modest reductions in regional oxidant, carbon monoxide, and particulate concentrations due to electric car use will probably be accompanied by moderate increases in sulfur dioxide concentrations re-

sulting from increased electric power plant emissions within the Los Angeles region due to electric car recharging.

4. Energy benefits of electric car use can be significant. Advancing battery technology should keep electric cars moderately more energy-efficient, where petroleum is the basic fuel, than the average ICE car; but electric cars would be little or no more efficient than ICE subcompacts which offered equal accommodations and performance. An increasing number of electric cars in Los Angeles could be recharged from coal or nuclear power, according to current facilities planning of utilities serving the region; thus by 1990 electric car use of 40% could reduce regional automotive petroleum use by 26-33% if these plans materialize.

5. Regional economic impacts of substantial electric car use would be moderate. Electric car use will entail shifts in Los Angeles regional transportation employment from automotive support, principally service stations, to battery manufacturing; but at most only about one percent of the regional labor force would be directly affected and this would be accomplished over a long time period. The life-cycle costs of lead-acid and nickel-zinc battery cars will be near those of standard-size ICE cars and significantly higher than those of ICE subcompacts; to the extent that they replace subcompacts, these electric cars will reduce consumer resources available for non-transportation expenditures. The zinc-chlorine and lithium-sulfur battery cars, however, may actually have lower life-cycle costs than ICE subcompacts if the ambitious cost and life goals of the respective battery developers are achieved.

6. The free-market level of electric car usage appears most desirable in the Los Angeles region. The principal externalities to free-market auto transactions are air quality and

energy; but air quality in Los Angeles will be little affected by choices of electric rather than ICE cars, and petroleum savings will only be large if nuclear power plants planned for Los Angeles are built, an uncertain prospect at present. Without assurance of nuclear electric power, there seems to be insufficient justification for market intervention to ensure extensive regional use of electric cars.

7. Battery technology and specifically battery depreciation costs are the principal technological determinants of electric car desirability. The energy storage capability of even the lead-acid battery is adequate for significant urban use in the Los Angeles region, and the higher energy densities of advanced batteries are ample for more general use. Higher energy densities, however, will do little to make electric cars desirable and beneficial unless they are achieved with depreciation costs considerably less than those of the lead-acid batteries. Long life and low initial cost are thus vital objectives for battery research.

8. National use of electric cars would differ in important respects from regional use in Los Angeles. Materials markets and reserves would be seriously impacted by any of the battery types considered here, since twenty times as many electric cars would be involved. Petroleum savings could be larger, however, since electric utilities nationally are far less dependent on petroleum than in the Los Angeles region. If coal is used in the future to make synthetic gasoline, the amount of coal required for this purpose would be up to twice as much as would be required if the coal were burned directly in an advanced cycle electric generating plant and the electricity used in advanced battery cars.

2 CHARACTERIZATION OF FUTURE ELECTRIC CARS

2.1 APPROACH

The starting point for calculating impacts of electric cars is a quantitative description of their functional characteristics, such as performance, accommodations, range between recharges, energy consumption, materials requirements, and so on. The objective of this car characterization is simply to develop such descriptions for alternative future electric cars on a consistent basis. It is in no sense an exercise in detailed, innovative, or definitive design.

The electric cars characterized here are intended to be as useful as they can be made, but not to compete feature by feature with prospective ICE cars. Storage battery cars are not likely to achieve the range, acceleration, speed, and low cost of ICE cars simultaneously; some compromise is necessary. The best compromise will maximize the utility of the electric car in serving actual travel needs, rather than compete with ICE cars in particular characteristics such as acceleration or top speed.

Given the present battery technology, it is clear that range between recharges is critical for electric car utility. Without adequate range for a typical day's collection of urban trips, other virtues such as high acceleration and top speed, excellent accommodations and amenities, or low cost will be of limited value. Accordingly, after minimum performance requirements are established, driving range is given high priority and treated as a basic parameter in this electric car characterization. Range is initially analyzed parametrically as a function of car and battery weight. Then particular ranges for different battery technologies are selected to be compatible with reasonable battery costs and representative daily travel ranges.

2.2 PERFORMANCE REQUIREMENTS

Both present and prospective electric car batteries are relatively heavy for their energy storage capacity. With present technology, as much as 500 pounds of battery may be required to provide the mechanical energy obtainable from a single gallon of gasoline, despite the low efficiency of the gasoline engine relative to the electric motor. The battery equivalent of even a 10-gallon tank of gasoline will be prohibitively heavy until improved battery technology becomes available.

In consequence, energy efficiency and minimization of energy storage requirements are far more important in electric cars than in ICE cars. For these reasons, practical electric cars are usually conceived as subcompacts of relatively low performance.

Performance requirements were set in this characterization at minimal levels for maintaining traffic flow. Average accelerations of 5 mph per second from 0 to 30 mph, and 4 mph per second from 0 to 40 mph, were selected to ensure adequate traffic volumes through signalized intersections. This is at the low end of the performance spectrum spanned by current conventional subcompacts--a bit less than that of the Pinto or Vega, but about equal to that of the common VW Beetle. A top speed of 65 mph was chosen to enable freeway cruising at moderate speeds with an acceleration reserve for on-ramps and minor grades.

Safety in accord with prospective Federal motor vehicle standards is taken as a fundamental requirement for these electric cars. Accommodations for four passengers are assumed, to ensure general utility for family, social, and recreational trips as well as work and business trips. A modest heater capability appropriate to the mild Los Angeles winters is assumed to be provided from waste heat given up by the propulsion motor and its controller. No air conditioning is assumed, because its relatively high energy demand could significantly reduce range between recharges. Moreover, in 1973 only a minority (30%) of subcompacts sold in the US were equipped with air conditioning.

2.3 BATTERY CHARACTERISTICS

Because future battery technology is the critical issue in electric car capability and cost, a brief survey of the field was made. From it four representative future batteries for electric cars were characterized approximately as in Table 2.1. There are, of course, other promising battery types; but their prospects are encompassed in the range spanned by the entries in Table 2.1.

The prospective energy storage of these batteries is further described in Fig. 2.1 for different power levels, which correspond to different rates of discharge. Particularly in the case of lead-acid batteries, single figures for energy density such as those offered in Table 2.1 can only be rough approximations because of their dependence on discharge rate. In calculating ranges in this characterization, the curves of Fig. 2.1 rather than the particular energy densities (and associated efficiencies) of Table 2.1 were employed.

The lead-acid battery specific energy projected for 1978 is based on developmental batteries which have actually been operated in electric cars. All are of the golf-cart type, which offers relatively high energy density at high discharge rates with a life of several hundred deep discharge cycles. In these respects the electric car batteries represent a compromise between long-life industrial traction batteries and high-energy starting-lighting-ignition batteries for automotive use. While their projected specific energy can probably be achieved, the simultaneous achievement of the higher cycle life in Table 2.1 is quite uncertain; accordingly, the indicated range of lifetimes has been carried through the impact analysis.

The nickel-zinc battery characteristics in Table 2.1 are based on recent results and objectives of a development program at Gould, Inc. The potential performance of the nickel-zinc couple with aqueous potassium hydroxide electrolyte has long been recognized, but cycle life

TABLE 2.1

SUMMARY PROJECTION OF BATTERY CHARACTERISTICS

(Source: Task Report 1, Table 5.1)

	Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur
Specific Energy,[*] W·hr/lb	13	44	70	140
W·hr/kg	29	96	155	310
OEM Cost Per Unit of Capacity, $/kW·hr	20-25	25-35	10-15	15
Life, Deep-Discharge Cycles	250-750	200-400	500-1,000	3-5 years
Energy Efficiency,[*] Percent	46	66	70[**]	62[†]
Availability	1978	1980	1985	1990

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[*] Assumes discharge in urban driving and overnight recharge.

[**] Includes allowance for electrolyte circulation pumps and for refrigeration required during charging.

[†] Includes allowance for heater to maintain battery operating temperature.

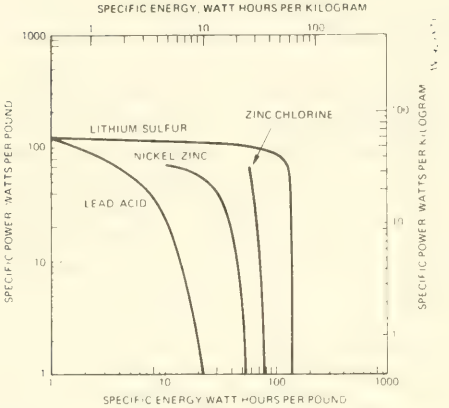

Figure 2.1. Assumed Battery Capabilities (Source: Task Report 1, Fig. 5.15)

problems have heretofore prevented applications. The cycle life shown in Table 2.1 is a projection based on current laboratory results for deep discharges. As discharge depth is decreased, cycle life is expected to increase in inverse proportion; i.e., the total energy delivered by the battery during its life is expected to be independent of cycle depth.

The zinc-chlorine battery characteristics in Table 2.1 are based upon objectives of a five-year development program being conducted by Energy Development Associates, Inc. To allow for unforeseen problems, availability is here projected in 1985. This battery might more informatively be described as an energy system, since it utilizes a chlorine hydrate store separate from the electrode stack and includes pumps for electrolyte circulation and a refrigerator for forming the chlorine hydrate.

The lithium-sulfur battery characteristics in Table 2.1 are derived from a recent development program at Argonne National Laboratory. They refer to a high-performance, high-temperature battery with molten lithium and sulfur electrodes, rather than a less-ambitious battery with solid lithium alloy and metal-sulfide electrodes which is the current focus of development. This battery, unlike the others, has never been operated in any electric vehicle; it is in a much earlier stage of development, and consequently its commercial availability, even by the distant date projected in Table 2.1, is relatively uncertain. The molten salt electrolyte must be operated at temperatures near 375°C, which gives rise to very difficult problems of corrosion and dissolution. Moreover, a heater is required except during periods of battery discharge and charge when internal energy losses are sufficient to maintain the required temperature; at an estimated 3 kilowatt-hours per day, heater energy is a significant factor in the overall energy efficiency, which otherwise would be near 80% in Table 2.1. As with the zinc-chlorine system, the cycle life of Table 2.1 is a goal yet to be corroborated by laboratory results.

2.4 PARAMETRIC RANGE ANALYSIS

With the electric car performance requirements and battery characteristics of Secs. 2.2 and 2.3, driving range between recharges was estimated as a function of battery weight to show a range of reasonable possibilities for each battery type. Ranges were evaluated by a computer simulation consisting of a road load model and an elementary battery discharge model. The road load model calculated power and energy requirements for each time increment in an urban driving cycle. The battery discharge model estimated the fraction of the battery capacity used in meeting each time increment's power and energy requirement, by reference to the curves of Fig. 2.1.

The SAE Metropolitan Area Driving Cycle shown in Fig. 2.2 was used for the range calculations. Comparisons showed that it gave results within a few percent of those obtained for the much more complicated

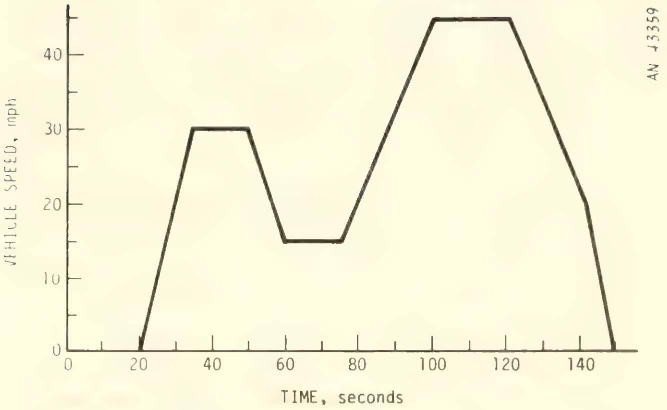

Figure 2.2. SAE Metropolitan Area Driving Cycle (SAE J-227)

Federal driving cycle. Additional comparisons showed that the computer model could reasonably reproduce actual measurements of electric auto ranges on these SAE and Federal driving cycles.

The basic parametric results produced by the computer model are shown in Fig. 2.3. In obtaining these results, the frontal area of the electric car was taken to be 22 square feet. Its aerodynamic drag coefficient was taken as 0.4, midway between the value of 0.3 achieved by the VW Karmann Ghia and the values of 0.5 to 0.6 typical of US passenger cars. Special low-loss tires were assumed, with 42% of the rolling resistance of conventional bias-ply tires. A DC series traction motor and thyristor controller were assumed, with power adequate to meet the performance requirements described in Sec. 2.2. Average electrical efficiency (from controller input to motor output) was taken as 80%, and average mechanical efficiency (from motor output to rear wheels) as 90%. A two-speed automatic transmission, which raises motor speed and efficiency at low road speeds, is implicit in these figures.

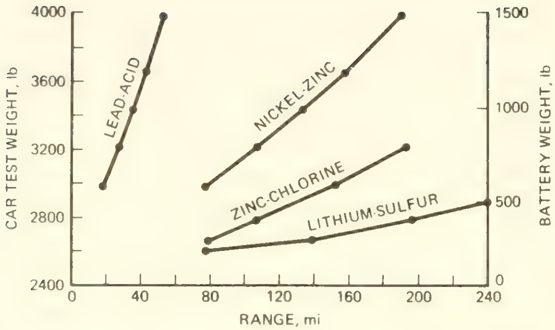

Figure 2.3. Urban Driving Range of Future Four-Passenger Electric Cars (SAE Metropolitan Area Driving Cycle) (Source: Task Report 1, Fig. 6.2)

The longer ranges in Fig. 2.3 may be conservative, since lengthy urban trips will probably involve less stopping and starting than the SAE driving cycle of Fig. 2.2. The ranges of these cars on level ground at steady moderate speeds are more than twice those shown.

Battery life is commonly considered to be ended when capacity has dropped to 60% of its initial value. Thus the range capability of Fig. 2.3 would decrease substantially with battery age. The lead-acid and nickel-zinc batteries are somewhat temperature-sensitive; at 32°F, the range of the lead-acid car may be reduced by about 30% of that shown.

2.5 CAR CHARACTERISTICS

A preliminary calculation showed that depreciation costs for lead-acid batteries might range up to six cents per mile with increasing range capability and battery weight, even with optimistic battery life assumptions. Thus it can be expensive to buy range capability which is seldom needed. Preliminary car usage data showed that a 55-mile daily range was generally adequate for second-car applications, while 140-mile daily range was sufficient for most urban driving. Accordingly, these were selected as characteristic ranges for the lead-acid car and the advanced-battery cars, respectively. After these selections and after completion of car characterization, detailed car cost and usage analyses were performed, as described in Secs. 7 and 8.

The characteristics of cars with the selected ranges are summarized in Table 2.2. In addition to weights from Fig. 2.3, they show energy consumption rates measured at the battery charger input and at the motor controller input. Controller inputs were derived directly from the computer road load model; battery charger inputs were estimated by several methods, each assuming a high charger efficiency of 97%. For the zinc-chlorine and lithium-sulfur batteries, the overall charge-discharge efficiency goals stated by the developers were utilized. For the lead-acid battery an overnight charging efficiency of 83% was deduced from typical recharging recommendations; an equal efficiency was assumed for the nickel-zinc battery; and for both, energy to be replaced was assumed to be that withdrawable from the battery at a low rate of discharge--although in practice something less would be required, depending on how high the actual discharge rate was.

Though they are based on simple and approximate calculations, the range and energy consumption estimates do not appear unreasonable in the light of experience to date. Table 2.3 presents results of energy consumption tests on several electric cars, both as reported and normalized per pound of test weight. In comparison, the energy consumption of the lead-acid battery car characterized here appears a bit low at a constant 30 mph and a bit high in urban driving. Urban driving is the important case for impact analysis; here the characterization's energy use estimate is only 10% above the range reported for the Sundancer, the only car of Table 2.3 tested on the SAE driving cycle used in the characterization. It is noteworthy that the Sundancer and the lead-acid car characterization

TABLE 2.2

SUMMARY PROJECTION OF ELECTRIC CAR CHARACTERISTICS

(Source: Task Report 1, Tables 7.1 and 8.1, Fig. 6.3)

Battery Type		Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur
Test Weight,*	lb	3,975	3,530	2,950	2,655
	kg	1,803	1,602	1,338	1,204
Battery Weight,	lb	1,500	1,090	570	300
	kg	681	495	259	136
Urban Driving Range,**	mi	54	144	145	139
	km	87	232	233	224
Range at 30 mph,	mi	183	375	309	317
	km	295	604	497	510
Overall Energy Use**,†					
	kW·hr per mi	0.79	0.51	0.41	0.45
	kW·hr per km	0.49	0.32	0.25	0.28
Battery Energy Output**					
	kW·hr per mi	0.35	0.33	0.28	0.27
	kW·hr per km	0.22	0.21	0.17	0.17

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*Includes 450-lb payload.

**SAE Metropolitan Area Driving Cycle.

†From power lines. Assumes 97% battery charger efficiency and overnight recharge; includes allowances for pumping and refrigeration in the zinc-chlorine system, and for heating in the lithium-sulfur system.

Range 54 miles
65 mph Top Speed
because acceleration is limiting

TABLE 2.3

COMPARATIVE ENERGY USAGE OF LEAD-ACID BATTERY CARS

(Source: Task Report 1, Table 8.2)

Car	Test Weight, lb	Energy Use, kW·hr/mi		Specific Energy Use, W·hr/mi/lb	
		30 mph	Urban Driving*	30 mph	Urban Driving*
GM 512	1,650	0.196	---	0.119	---
ESB Sundancer	2,000	---	0.31-0.37	---	0.155-0.185
EFP Mars II	4,650	0.4	---	0.086	---
EFP Electrosport	5,980	0.447	---	0.075	---
Four-Passenger Characterization	3,975	0.234	[illegible]	[illegible]	[illegible]

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*SAE Metropolitan Area Driving Cycle (J 227).

are similar in key respects: both have DC traction motors with chopper controllers, two-speed transmissions, and high-efficiency tires; and both have high-performance batteries constituting 38% of car test weight. In range tests, 50-55 mi on the SAE Metropolitan Cycle of Fig. 2.2 was reported for the Sundancer, bracketing the 54-mile simulation result in Table 2.2.

Battery energy outputs per mile in Table 2.2 are equivalent to average battery power outputs of 6.5 to 8.4 kW. At the estimated average efficiency of 80%, 1.2 to 1.7 kW of heat would be available from the motor and controller, enough to maintain comfortable interior temperatures even on overcast days with 40-50° ambient temperatures. In Los Angeles, the average minimum daily temperature in January, the coldest month of the year, is 45°.

Allowances for accessory power are not included in the figures of Table 2.2, but with the exception of air conditioning, accessory power consumption would be relatively low. Lights, windshield wipers, blowers, and radio would require only about 225 W total, less than 3% of the average battery output power implicit in Table 2.2. Power steering and brakes together would consume even less; they would be especially desirable for the heavier lead-acid and nickel-zinc battery cars. Air conditioning, on the other hand, would require about 1.3 kW, or 15-20% of average battery output power for propulsion; driving range would thereby be reduced by 25% or more from the figures of Table 2.2.

The zinc-chlorine and lithium-sulfur batteries for cars in Table 2.2 are relatively light; their size could be readily increased to allow air conditioning, improved accommodations, higher performance, and extended range between recharges. At the other extreme, such changes would be much more costly in the lead-acid battery car, where battery weight is high and capabilities marginal to begin with.

The cars characterized in Table 2.2 are conceived as subcompacts, with performance at the low end of the current subcompact ICE car market. With lead-acid batteries, the car might be sized and arranged as suggested in the sketch of Fig. 2.4, which allows adequate crush distance for occupant protection to high standards. The zinc-chlorine and lithium-sulfur batteries are each a single package rather than a collection of modular units as sketched; they might be placed ahead of the car occupants, or (with change of occupant position) under the front seat. Cases for such batteries would protect against accidental release of battery materials, and could be designed to contribute energy absorption capabilities as well in a crash.

The materials required by the cars of Table 2.2 differ from those of conventional cars primarily because of the batteries. Table 2.4 summarizes battery material requirements.

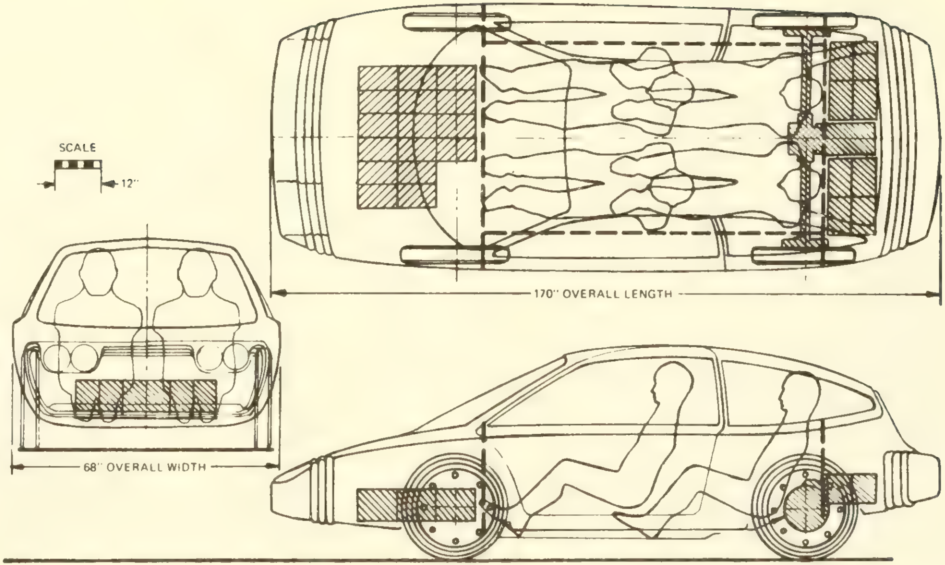

Figure 2.4. Four-Passenger Electric Car Concept (Source: Task Report 1, Fig. 3.8)

TABLE 2.4

BATTERY MATERIAL WEIGHTS

(Source: Task Report 1, Table 8.3)

	Pounds Per Car
	Lead-Acid Battery
Lead	481
Lead Oxide	489
Antimony	24
Electrolyte	426
Polypropylene	56
Filled Polyethylene	20
Epoxy	4
Total Weight	1,500
	Nickel-Zinc Battery
Nickel	362
Zinc Oxide	328
Potassium Hydroxide	109
Electrolyte	96
Polypropylene Oxide	64
Plastic Separators	33
Band and Terminals (Copper or Nickel)	11
Miscellaneous	87
Total Weight	1,090
	Zinc-Chlorine Battery
Zinc	64
Chlorine	69
Water	200
Titanium	34
Frames, Electrodes, Mountings	34
Heat Exchanger (Titanium and Coolant)	17
Support Structure	17
Miscellaneous	135
Total Weight	570
	Lithium-Sulfur Battery
Lithium	17
Sulfur	66
Electrolyte	63
Porous Graphite	23
Porous Stainless Steel	29
Stainless Steel Housing	61
Aluminum Casing	7
Thermal Insulation	16
Insulation, Connectors, Misc.	18
Total Weight	300

Much smaller electric cars were also characterized in this study. Intended only for neighborhood travel, they seated two passengers and offered neither the acceleration nor speed desirable for freeway use. In curb weight, they ranged from 1/2 to 2/3 that of the four-passenger cars, with similarly reduced energy consumption and battery depreciation costs. Because these cars offered so much less capability than conventional cars now in use, and were so sharply limited in passenger capacity and performance, no clear area of applicability emerged for them in the analyses of automobile usage patterns discussed in Sec. 8. Accordingly, they were not carried through the impact analysis, and are not considered further here.

3 BASELINE POPULATION AND TRANSPORTATION PROJECTIONS

The "baseline" projections used in this study outline the prospects for the Los Angeles region in the absence of electric cars, providing a benchmark relative to which the impacts of future electric car use may be measured. These baselines are often crucial in importance. If, for example, high air quality is already to be assured through other means, further pollution reductions due to electric cars may be minor in both amount and importance; or if nuclear energy is to supplant petroleum as the major source of electricity in Los Angeles, then petroleum savings due to electric car use may be greatly increased.

This section presents the baseline regional population and transportation projections. The air quality, energy, and economic baselines are described subsequently in Secs. 4, 5, and 7, each with its associated analysis of electric car impacts.

3.1 BASIS OF THE PROJECTIONS

The study area, California's South Coast Air Basin, is outlined in Fig. 3.1. A region of roughly 10,000 square miles, it is bounded by the Pacific Ocean and by inland mountains, accommodates a population approaching 10 million persons, and includes greater Los Angeles.

Baseline regional projections in this study rest on two basic assumptions: first, that population growth in the region will be moderate, considerably less than in the past; and second, that environmental and economic progress will be balanced without systematic subordination of either one to the other. At the present time, a much-reduced rate of population growth is already a matter of record, but the long-term balance of economic and environmental priorities remains to be fully established.

The baseline projections in this study further assume that there will be no dramatic technological breakthroughs, such as practical solar-electric power generation, or high-capacity personal rapid transit and dual-mode transportation systems. Though worthy of consideration elsewhere, such developments are beyond the scope of this analysis.

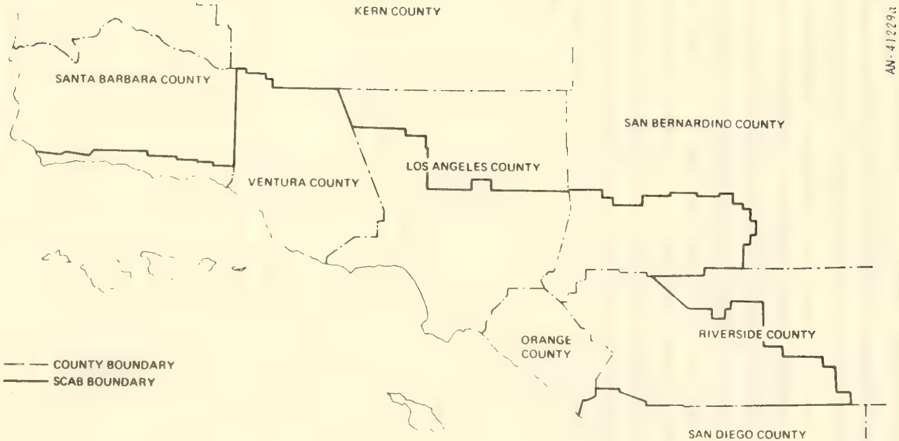

Figure 3.1. California's South Coast Air Basin (Source: Task Report 2, Fig. 1.1)

3.2 POPULATION BASELINE

The population projections shown in Fig. 3.2 were developed for the South Coast Air Basin from county-by-county projections of the California Department of Finance and the Southern California Association of Governments. In years past, the Series D projection (which included substantial net immigration) was generally accepted for the region. Recently, however, an end to net immigration and a continued decline in regional birth rates has led the agencies concerned to move towards the Series E projection in Fig. 3.2, which was accordingly adopted in this study. It assumes zero net migration and a completed fertility rate of 2.1, conditions leading eventually to population stabilization: the growth implicit in this Series E projection is only 0.8% per year for the period 1970-2000. Even lower growth is conceivable: during the

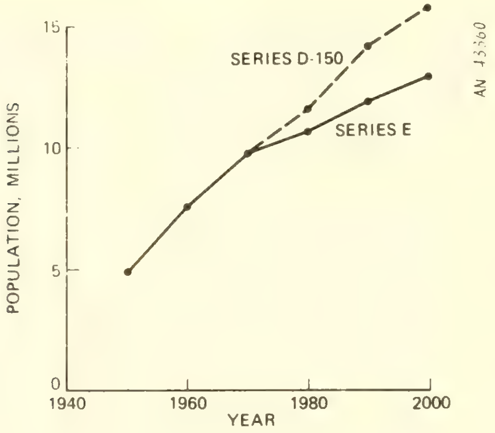

Figure 3.2. Population of the South Coast Air Basin (Source: Task Report 1, Tables 2.1, 2.3, 3.1)

early 70's, the population of Los Angeles County actually declined, and current birth statistics are following an even lower trend line, Series F.

3.3 TRANSPORTATION BASELINE

As in other cities across the nation, freeway construction in Los Angeles has slowed considerably from its pace in the 50's and 60's. Though almost half the officially planned and adopted freeway network for the Air Basin had been completed in 1972, present indications are that only a small fraction of the remainder will be built. Nonetheless, it appears that freeway route mileage in the Basin will continue to grow somewhat faster than the population, at an annual rate of about 1-1/2%. Moreover, freeway capacity should expand even faster as lanes are added along existing routes.

Continued growth in automobile ownership rates is projected for the Air Basin, as shown in Fig. 3.3. The region has historically had more automobiles per capita than the United States or even the rest of California. The future growth projected in Fig. 3.3 follows projections based on detailed regression analyses involving household size, type, and income which were developed at the Los Angeles Regional Transportation Study (LARTS).

The usage of individual automobiles has been relatively stable for many years. In the United States as a whole (except during the war years), average annual mileage per car has taken three decades to increase from 9,000 to 10,000. California auto usage in recent years has been below the national average. Future usage growth in line with the national trend shown in Fig. 3.4 is projected for this study.

Table 3.1 presents baseline auto projections for the South Coast Air Basin. These projections were developed by combining the population, auto ownership, and auto usage projections of Figs. 3.2-3.4, and adding figures on trip frequency, trip speed, and freeway usage developed by LARTS through detailed network modeling.

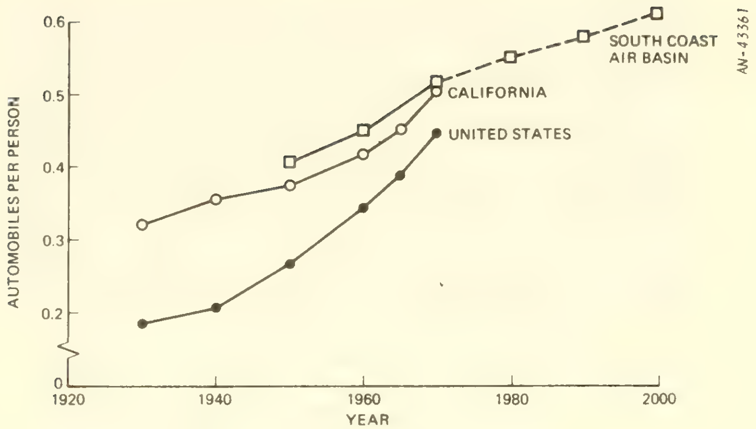

Figure 3.3. Automobiles per Person
(Source: Task Report 3, Fig. 4.1)

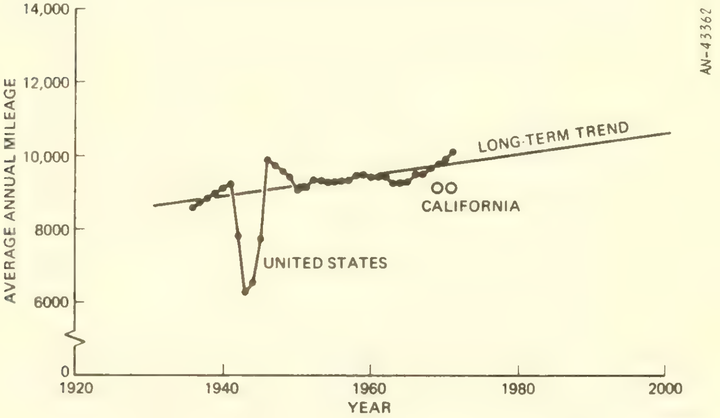

Figure 3.4. Average Annual Passenger Car Mileage
(Source: Task Report 3, Fig. 5.2)

TABLE 3.1

BASELINE AUTO TRAVEL PROJECTIONS, SOUTH COAST AIR BASIN
(Source: Task Report 3, Table 5.5)

	1980	1990	2000
Daily Vehicle-Miles, millions	167	196	228
Percent on Freeways	39	42	45
Percent on Streets	61	58	55
Daily Miles Per Vehicle	28.3	29.2	30.0
Daily Trips Per Vehicle	4.6	4.6	4.6
Daily Minutes Per Vehicle	53	54.7	56.2
Miles Per Trip	6.15	6.35	6.52
Minutes Per Trip	11.5	11.9	12.2
Average Speed, mph	32.0	32.0	32.0

Despite ambitious regional plans and a prospective multi-billion-dollar investment in new facilities and equipment, public transit will apparently play only a minor role in future regional travel. A system recommended in 1973, combining 140 miles of grade-separated rapid transit with an expanded fleet of 2740 buses, was expected to divert only 2.4% of motorists in its service area to rapid transit in the year 1990.

Overall, the outlook in Table 3.1 is for relative stability: little change in average auto usage, or travel speeds, or congestion levels, and only moderate growth in total regional automobile travel. More rapid growth in regional population and auto ownership would have relatively little effect on electric car impacts. Rapid growth in average automobile usage, however, could significantly increase daily driving ranges relative to practical capabilities of nearer-term electric cars, thus reducing their applicability. Though the stability of the usage trend in Fig. 3.4

makes this seem unlikely, regression analysis at LARTS has led in the past to projections far above the 1990 daily mileage in Table 3.1.

Future auto energy consumption is projected as shown in Fig. 3.5. Although auto fuel economy has been declining for many years, as indicated by DOT data for cars on the road and EPA data for new cars, the projection anticipates major improvements: 50% by 1984 and 100% by the end of the century. Powerful economic and political forces have already begun a movement in this direction; and though the gasoline "crisis" of early 1974 has eased, these forces remain at work: petroleum reserves are dwindling, prices remain much higher than in previous years, international payments deficits accumulate rapidly, and the US desires independence of politically-inspired embargoes by oil-producing nations. The projection of Fig. 3.5 is in line with a legislative request to Congress planned in early 1974 by EPA (circle 1 in Fig. 3.5), and with the goal of legislation actually

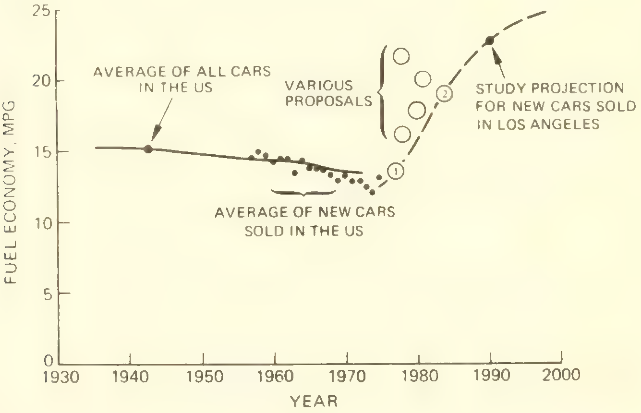

Figure 3.5. Automobile Fuel Economy (Source: Task Report 3, Fig. 7.4)

passed in December, 1973, by the US Senate (S.2176) to encourage auto fuel economy (Circle 2 in Fig. 3.5). Though this projection represents a dramatic reversal of past trends, it remains less ambitious than other legislative goals and technology-development goals advanced during 1973 (unnumbered circles in Fig. 3.5). Part of the projected economy increase may be attributed to a continuation of the trend to smaller cars, in which Los Angeles has led the nation for many years. In 1972, 45% of the automobiles sold in the area were compacts and subcompacts; by 1990, this proportion is projected to rise to 65%, mostly subcompacts. The remainder of the economy improvement will require more efficient power trains and weight reductions within each auto size class. If the projection is realized, total gasoline consumption in the South Coast Air Basin will decline by almost 1/4 during the remainder of this century, despite the increase in travel shown in Table 3.1.

The projection of Fig. 3.5, though clearly within technological reach, is relatively optimistic. The data points in Fig. 3.5 for 1974 and 1975 cars, which became available after the projection was made, are encouraging evidence that the anticipated economy upturn has begun, but it may nevertheless fall far short of the projection. In that case, the savings of energy and petroleum due to electric car use could be substantially increased in both magnitude and importance.

4 AIR QUALITY IMPACTS

4.1 BACKGROUND AND ASSUMPTIONS

In this study of electric car impacts, the largest single analytic effort was devoted to air quality. There were several reasons for this emphasis. First, air quality has been an important problem in the Los Angeles area for over thirty years. Second, Los Angeles air pollution has been primarily vehicular in origin: in 1970, almost 100% of carbon monoxide emissions and about two-thirds of reactive hydrocarbons and nitrogen oxides emissions were from motor vehicles. Third, the use of electric cars instead of conventional cars drastically alters automotive air pollutant emissions.

The quantitative impacts of electric car use on air pollution will depend strongly on the extent to which pollution from conventional automobiles is controlled. California legislation to limit automotive emissions first took effect in 1963; Federal legislation followed in 1968. With the Clean Air Act of 1970, the Federal government moved towards a 90% reduction of automotive pollutant emissions relative to 1970 by the year 1977. As Table 4.1 shows, the major part of this reduction is to take effect progressively from 1974 to 1977--and California, in recognition of its particular air quality problems, is to lead the rest of the nation in the tightening of controls.

Though the scheduled emissions standards of Table 4.1 remain effective as of this writing, legislation is being proposed and developed to delay and relax the final steps in the schedule. It is thus quite possible that the imposition of the 1976 requirements will be delayed two years, and that the final reduction of nitrogen oxides emissions from 2.0 to 0.4 grams per mile will be delayed indefinitely.

In developing baseline projections of air quality for this study, it was assumed that the emissions standards of Table 4.1 would be applied,

TABLE 4.1

EXHAUST EMISSION STANDARDS FOR LIGHT-DUTY VEHICLES

(Source: Task Report 7, Table A.3)

	Emission Standards, grams per mile		
	Hydrocarbons	Carbon Monoxide	Nitrogen Oxides
1974 Federal	3.4	39	3.0
California	3.2	39	2.0
1975 Federal	1.5	15	3.1
California	0.9	9.0	2.0
1976 Federal	0.41	3.4	2.0
California	0.41	3.4	2.0
1977 Federal	0.41	3.4	0.40
California	0.41	3.4	0.40

as existing law requires. In recognition of the possibility of future revisions, however, projections for an alternative baseline in 1980 were also developed. This case, in which standards are delayed and relaxed as discussed above, is called "1980D" in the following pages.

The Clean Air Act of 1970 has led not only to emissions standards, but to the air quality standards summarized in Table 4.2. At present, Federal law requires compliance with these standards in Los Angeles by 1977. Since it has appeared unlikely that the scheduled reduction of pollutant emissions from both vehicular and stationary sources would be sufficient to reach compliance, stringent transportation controls are being developed for application in the Los Angeles region. But just as relaxation of emission standards is possible, so also are delays and revisions in air quality standards and related controls.

TABLE 4.2

NATIONAL AMBIENT AIR QUALITY STANDARDS

(Source: Task Report 6, Table 7.1)

	Level Not to Exceed		
Pollutant	Primary	Secondary	
Sulfur Dioxide	80 $\mu g/m^3$ (0.03 ppm)	60 $\mu g/m^3$ (0.02 ppm)	(a)
	365 $\mu g/m^3$ (0.14 ppm)	260 $\mu g/m^3$ (0.1 ppm)	(b)
Particulate Matter	75 $\mu g/m^3$	60 $\mu g/m^3$	(c)
	260 $\mu g/m^3$	150 $\mu g/m^3$	(b)
Carbon Monoxide	10 mg/m^3 (9 ppm)	Same	(d)
	40 mg/m^3 (35 ppm)		(e)
Photochemical Oxidants	160 $\mu g/m^3$ (0.08 ppm)	Same	(e)
Hydrocarbons	160 $\mu g/m^3$ (0.24 ppm)	Same	(f)
Nitrogen Oxides	100 $\mu g/m^3$ (0.05 ppm)	Same	(a)

(a) Annual arithmetic mean.

(b) Maximum 24-hr concentration not to be exceeded more than once a year.

(c) Annual geometric mean.

(d) Maximum eight-hour concentration not to be exceeded more than once a year.

(e) Maximum one-hour concentration not to be exceeded more than once a year.

(f) Maximum three-hour concentration (6-9 AM) not to be exceeded more than once a year.

Because transportation controls assuring compliance in 1977 with the air quality standards would be very severe, the baseline projections of this study have assumed that such strict controls will not be imposed (see Sec. 4.4), and consequently that the air quality standards will not necessarily be met as presently scheduled. In the absence of such controls, vehicular emissions and air pollution levels would be higher than otherwise, and both the size and the desirability of reductions due to electric cars would be enhanced.

4.2 METHODS AND OBJECTIVES

In accord with initial planning for an efficient and effective analysis, this study addressed air pollution in three steps: emissions projections, photochemistry simulations, and simple "rollback" calculations.

The emissions projections show prospective air pollutant emissions in considerable spatial, temporal, and chemical detail, both with and without the use of electric cars. The changes in total emissions by themselves indicate what electric cars can do. But they do not tell the whole story: besides changing total emissions, electric cars will shift emissions from streets and freeways to power plants and from daytime to nighttime, and will also alter the mixture of pollutants emitted. The net effect on air quality depends significantly on the interaction of all these changes in the photochemical diffusion processes through which "secondary" pollutants appear. Most important among secondary pollutants are the oxidants of Table 4.2. Photochemical oxidants have been a serious problem in Los Angeles, repeatedly reaching concentrations triggering local health alerts.

To investigate the effects of the detailed emissions changes on secondary photochemical pollutants, a computer simulation developed at General Research Corporation for the Los Angeles area, DIFKIN, was employed. The basic operation of DIFKIN is illustrated schematically in Fig. 4.1.

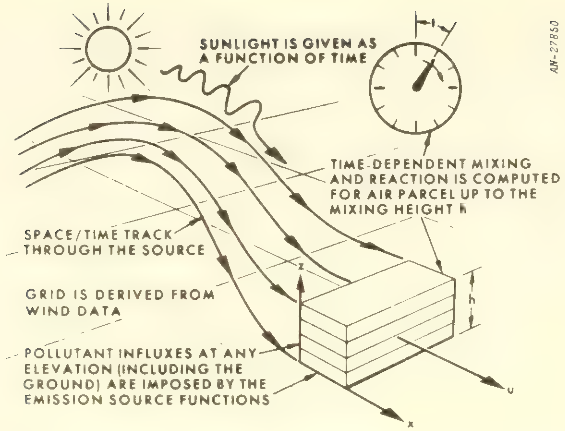
AN-27850
SUNLIGHT IS GIVEN AS A FUNCTION OF TIME
TIME-DEPENDENT MIXING AND REACTION IS COMPUTED FOR AIR PARCEL UP TO THE MIXING HEIGHT h
SPACE/TIME TRACK THROUGH THE SOURCE
GRID IS DERIVED FROM WIND DATA
POLLUTANT INFLUXES AT ANY ELEVATION (INCLUDING THE GROUND) ARE IMPOSED BY THE EMISSION SOURCE FUNCTIONS
z
h
u
x

Figure 4.1. Schematic GRC Photochemical Diffusion Model for Air Quality Simulation (Source: Task Report 6, Fig. 3.1)

As a check on the DIFKIN results and to estimate primary pollutant concentrations not computed by the simulation, projections were also made by means of "linear rollback" calculations. In these calculations, changes in pollutant levels are simply assumed to be proportional to changes in aggregate daily emissions. Largely because simulations are difficult to operate and validate, rollback has been widely accepted as an analytic tool despite its evident theoretical limitations.

The basic objective of the air pollution analysis has been to determine changes in air quality due to future electric car use. The importance of a given change depends, however, on the absolute level of air quality at which it is effective. Thus a secondary objective has necessarily been to forecast absolute air quality levels in the absence of electric car use. Though such forecasts are admittedly contentious, they are essential to electric car impact assessment.

4.3 POLLUTANT EMISSIONS

Detailed projections of pollutant emissions were made for the heavily populated subarea of the South Coast Air Basin shown in Fig. 4.2, hereafter referred to as "Los Angeles and Environs." Vehicular and distributed stationary sources were aggregated by a system of 2 × 2 mile grid squares. Future vehicle movements and emission factors for streets and freeways, treated separately, were developed from the emission standards of Table 4.1 and the detailed travel forecasts of the Los Angeles Regional Transportation Study, adjusted for this study's population and transportation baselines (see Sec. 3). Distributed stationary sources (such as gasoline marketing and dry cleaning) were developed from land use plans of the Southern California Association of Governments. Finally, point-source emissions from power plants were derived from the baseline electric energy projection of Sec. 5, while those of oil refineries were projected in accord with actual facilities plans. The projections detail,

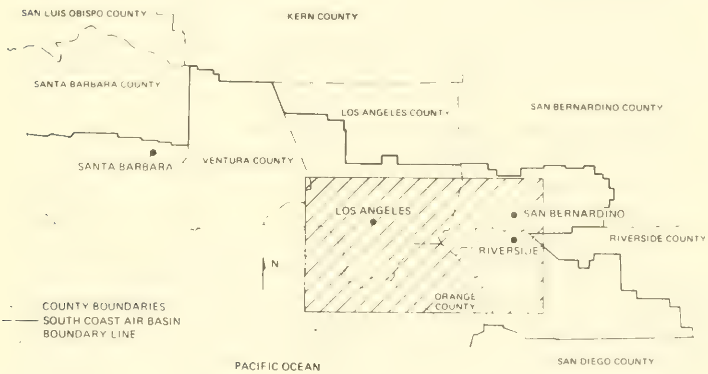

Figure 4.2. "Los Angeles and Environs", the Heavily Populated Subarea of the South Coast Air Basin Selected for Air Quality Analyses (Source: Task Report 7, Fig. A.2)

for each grid square, the hour-by-hour emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen, as required by the DIFKIN simulation. Sulfur dioxide and particulate emissions were only projected on an aggregate basis, as required for rollback calculations. Except as noted below, the projections apply to the average work day; emissions are typically less on weekends.

Table 4.3 summarizes the emissions by source projected for 1980, 1990, and 2000 in the absence of electric car use, and the actual 1970-71 emissions, for direct comparison.

In the case where auto emissions standards are delayed and relaxed, baseline projections for 1980 with and without the delay are shown in Table 4.4 for the most important vehicular emissions.

The projections of vehicular emissions in Table 4.3 were based on emissions measurements in the Federal Driving Cycle by model year, assuming for future years compliance with the standards of Table 4.1. These emissions were weighted by three factors: first, a deterioration factor accounting for the loss in effectiveness of emission controls with vehicle mileage; second, the fraction of daily vehicle miles contributed by vehicles according to their ages and use; third, a speed correction factor for speeds other than the driving cycle average speed. In general, all these factors are functions of vehicle model year.

5% of total vehicle miles traveled are assumed to be contributed by heavy-duty vehicles (over 6000 pounds). This figure is subject to some uncertainty, and varies significantly with locale. Because emissions standards for heavy-duty vehicles are less stringent than for automobiles, they contribute a disproportionate amount of the total vehicular emissions, as detailed in Table 4.5.

TABLE 4.3

BASELINE POLLUTANT EMISSIONS FOR LOS ANGELES AND ENVIRONS

(Source: Task Report 7, Tables 2.4-2.6 and C.1)

Four entries for each source and type are 1970-71 actual emissions, and projections for 1980, 1990, and 2000, in that order.

	Emissions, tons per day				
	Nitrogen Oxides	Hydrocarbons	Carbon Monoxide	Sulfur Dioxide	Particulates
Vehicular	455.0	918.4	9,719.7	20.2	82.2
	181.5	160.3	2,202.8	22.4	91.2
	75.5	72.3	1,084.2	24.4	99.2
	80.6	77.1	1,152.1	26.4	107.5
Stationary Area Sources	77.5	472.3	---	178.0	88.3
	106.0	160.7	---	195.3	96.9
	140.8	160.7	---	213.1	105.7
	181.1	160.7	---	227.7	112.9
Power Plants	78.6	---	---	175.0	7.5
	113.3	---	---	362.0	12.6
	116.2	---	---	372.0	12.9
	98.1	---	---	315.0	10.9
Oil Refineries	44.6	30.8	---	55.4	10.1
	48.8	33.7	---	60.6	11.0
	53.7	37.1	---	66.7	12.2
	57.6	29.8	---	71.5	13.0
Totals	655.7	1,421.6	9,719.7	428.6	188.1
	449.6	354.7	2,202.8	640.3	211.7
	386.2	270.1	1,084.2	676.2	230.0
	417.4	277.6	1,152.1	640.6	244.3

TABLE 4.4

1980 BASELINE VEHICULAR EMISSIONS FOR LOS ANGELES AND ENVIRONS WITH AND WITHOUT DELAYS IN IMPLEMENTING AUTO EMISSION CONTROLS

(Tons/Day)

(Source: Task Report 7, Table 2.7)

	Nitrogen Oxides	Hydrocarbons	Carbon Monoxide
With Delay	300.6	168.5	2,328.2
Without Delay	181.5	160.3	2,202.8

TABLE 4.5

PERCENTAGE CONTRIBUTION OF HEAVY-DUTY VEHICLES TO VEHICULAR AND TOTAL BASELINE EMISSIONS FOR LOS ANGELES AND ENVIRONS

(Source: Task Report 7, Table 2.9)

	Nitrogen Oxides		Hydrocarbons		Carbon Monoxide		Sulfur Dioxide		Particulates	
	Vehicular	Total	Vehicular	Total	Vehicular	Total	Vehicular	Total	Vehicular	Total
1980	18	7	23	10	31	31	9	0.3	8	3
1990	31	6	33	9	67	67	5	0.3	8	3
2000	31	6	33	9	67	67	9	0.4	8	3
1980D	11	6	22	10	29	29	9	0.3	8	3

The projections of power plant emissions in Table 4.3, principally nitric oxide and sulfur dioxide, assume no breakthroughs in emission control. The sulfur dioxide emissions are based simply on the use of 0.5% low-sulfur crude, without stack scrubbers. An increasing fraction of electric power for Los Angeles and environs is expected to be generated outside the air basin, and increasingly by nuclear power stations. In consequence, although total electricity consumption is projected to grow, the power generation that contributes air pollution in the air basin is projected to remain relatively constant. As shown in Fig. 4.3, the peak capacity of oil-fired power plants in the area is expected to increase modestly, but load factors will decrease as nuclear power becomes available to meet base demands.

For comparison with these baseline projections, emissions were also projected for selected levels of electric car use. Upper-bound usage levels were chosen, in order to show the maximum possible effects of electric cars on pollutant emissions and the resultant air quality. Usage levels of 20% in 1980, 80% in 1990, and 100% in 2000 were actually employed. Because they were selected and analysis begun before the results of the usage analysis of Sec. 8 were available, these figures are somewhat higher than the upper bounds estimated there.

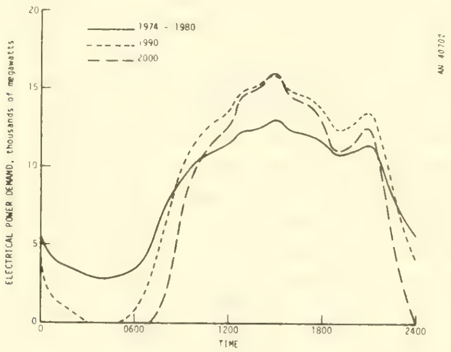

Figure 4.3. Projected Baseline Diurnal Power Demand on Oil-Fired Power Plants in Los Angeles and Environs for Peak Demand Month (August) (Source: Task Report 6, Fig. 5.2)

Projected emissions with upper-bound electric car use are shown in Figs. 4.4-4.8, together with the baseline emissions already presented in Table 4.3. In each figure, vehicular contributions to the total are indicated (for carbon monoxide, total and vehicular contributions are equal), and where appropriate, power plant emissions are also separately indicated. These figures show that electric cars will change total emissions relatively little, even at very high levels of use, primarily because of the relative future importance of emissions from stationary sources and heavy-duty vehicles after the cleanup of conventional automotive emissions now in progress.

Figure 4.9 shows similar projections for nitrogen oxides emissions, assuming a delay of two years in effecting the final reduction of auto emissions standards in Table 4.1, and assuming that the nitrogen oxides emission standard will remain at 2 grams per mile rather than reach 0.4 grams per mile. In this circumstance, total nitrogen oxides emissions would remain much higher, and the potential reductions due to electric cars are more significant.

In Figs. 4.4-4.8, overnight recharging of electric cars is implicit. On the day of peak annual demand, most of the recharging power will be generated in the Air Basin; this is shown in Fig. 4.10, which is to be compared with Fig. 4.3, the baseline case without electric cars. On the average day, however, an increasing fraction of recharge power will come from new power plants planned for construction outside the Basin; as a result, extra oil-fired generation in the Basin will be much less than shown in Fig. 4.10. The peak demand day typically occurs during the late-summer smog season. For worst-case analyses, then, the emission rates from power plants corresponding to Fig. 4.10 are used. For addressing average annual pollution levels, as is appropriate for sulfur dioxide and particulates, the lower average annual emissions due to electric car recharge are used.

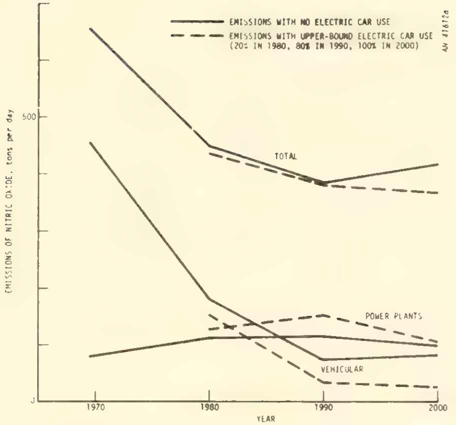

Figure 4.4. Projected Nitric Oxide Emissions (for Los Angeles and Environs, Without Delay of Emission Controls) (Source: Task Report 7, Fig. 3.2)

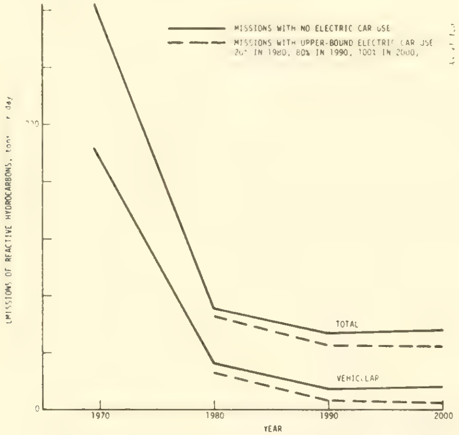

Figure 4.5. Projected Reactive Hydrocarbon Emissions (Source: Task Report 7, Fig. 3.3)

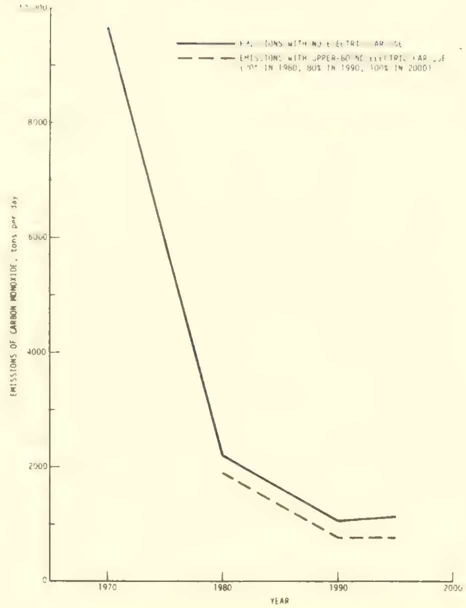

Figure 4.6. Projected Carbon Monoxide Emissions (Source: Task Report 7, Fig. 3.4)

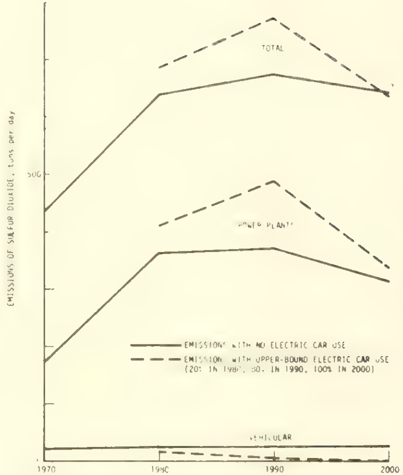

Figure 4.7. Projected Sulfur Dioxide Emissions (Source: Task Report 7, Fig. 3.5)

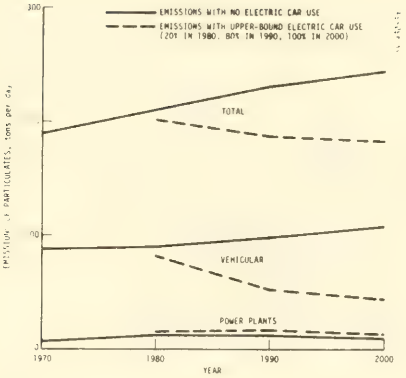

Figure 4.8. Projected Particulate Emissions (Source: Task Report 7, Fig. 3.6)

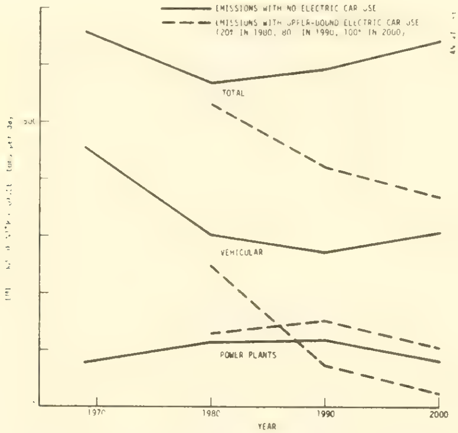

Figure 4.9. Projected Nitric Oxide Emissions (for Los Angeles and Environs, Delay of Emission Controls) (Source: Task Report 7, Fig. 3.7)

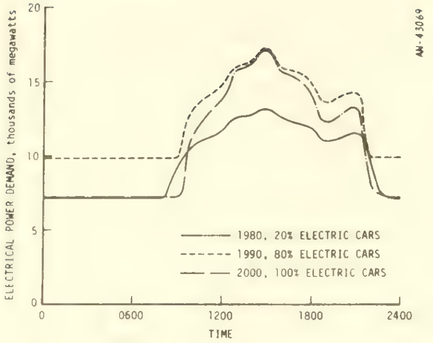

Figure 4.10. Projected Diurnal Power Demand on Oil-Fired Power Plants in Los Angeles and Environs for Peak Demand Month (August) (Source: Task Report 7, Fig. 3.1)

4.4 AIR QUALITY

The Federal air quality standards of Table 4.2 rely on a worst-case approach: they state for each pollutant a level allowable anywhere in the region only once annually, except for nitrogen oxides, for which only a maximum annual mean is established. To project corresponding future levels of air pollution, it is thus necessary to select the worst locations in the Air Basin for the various pollutants, and to establish for them representative meteorological conditions under which worst-case concentrations will arise.

These selections were made by a review of historical pollution records at measurement stations spanning the Air Basin, as shown in Fig. 4.11. The records show that conditions for smog in 1969 and 1970 were about the same, as summarized in Table 4.6. 1970 pollution maxima were used as the basis for rollback calculations, a convenience since 1970 is the reference year for Federal automotive emission reductions. For the

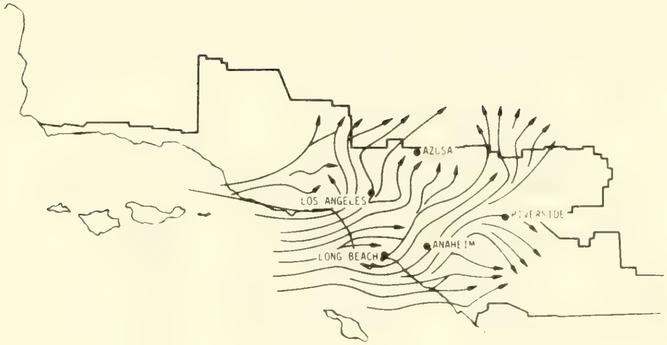

Figure 4.11. Typical Autumn Afternoon Airflow and Critical Sites in the South Coast Air Basin (Source: Task Report 6, Fig. 3.2)

TABLE 4.6

AUGUST-OCTOBER SMOG STATISTICS FOR 1969 AND 1970

(Source: Task Report 6, Table 3.1)

	1969	1970
Number of alerts	4	5
Number of days with eye irritation	65	57
Number of days on which oxidant > 0.1 ppm hourly average*	88	84
Number of days on which $NO_2 \geq 0.25$ ppm hourly average*	41	40
Number of days on which CO $\geq$ 10 ppm for 12 hours*	50	52

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*California state standard in force in 1970.

air quality simulations, meteorological conditions observed in the smog episode of late September 1969 were used, primarily because the available data is unusually extensive and had previously been used in the calibration and validation of the DIFKIN model.

Baseline worst-case pollutant concentrations are summarized in Table 4.7. In the case of secondary pollutants (ozone and nitrogen dioxide), both DIFKIN and rollback results are presented; they compare favorably, differing principally as would be expected because of changes in emissions mixes not accounted for in rollback. Both methods lead to the same conclusion: major decreases in secondary pollutants may be expected in future years. In the case of ozone, the Federal standard will nonetheless be exceeded on the worst-case day and probably several other days, but this is to be compared with excesses recorded during over 1500 hours at Riverside in 1970. No worst-case hourly or daily average is prescribed in Federal air quality standards for nitrogen dioxide, but the 1970 hourly maxima of Table 4.7 were accompanied by annual means about equal (in the worst Basin locations) to the standard. Thus the baseline projections of Table 4.7, representing a fourfold reduction in hourly maxima, suggest that the standard will be met. In contrast, the sulfur dioxide and particulate standards do not appear likely to be met.

Pollutant reductions due to upper-bound usage of electric cars are shown in Table 4.8. As in the case of emissions reductions, the low leverage of the electric cars--except for carbon monoxide--is apparent. Overall, the introduction of electric cars is likely to bring about a relatively small further change beyond that already in prospect due to improving control of conventional automobile emissions. In no case will the upper-bound usage of electric cars bring excessive pollutant concentrations of the baseline into compliance with Federal standards. In the case of sulfur dioxide, on the contrary, high electric car use moderately aggravates the already excessive pollutant concentrations in prospect. These concentrations appear in relatively small areas downwind of fossil-fuel power plants in the Basin; they may be reduced to acceptable levels when stack scrubbers are brought into use, as seems possible in the 1980s.

TABLE 4.7

BASELINE POLLUTANT CONCENTRATIONS, SOUTH COAST AIR BASIN

(Source: Task Report 7, Tables 3.9, 3.11, 3.14)

	Measure		Federal	1970	Projections				
Pollutant	Units	Period	Standard	Maximum	1980	1990	2000	1980D	Location
Ozone	pphm	1 hour	8	62	16^*	15^*	15^*	12^*	Riverside
					16	13	13	17	
NO_2	pphm	1 hour	---	43	12^*	10^*	11^*	13^*	Azusa/Anaheim
					14	13	14	17	
CO	ppm	1 hour	35	54	13	7	7	14	Lennox
SO_2	pphm	1 year	3.0	2.6	3.9	4.1	3.9	3.9	Reseda
Particulates	$\mu g/m^3$	24 hours	260	357	402	437	464	402	Anaheim

---

*DIFKIN simulation result; other projections from linear rollback.

TABLE 4.8

CHANGE IN POLLUTANT CONCENTRATIONS DUE TO ELECTRIC CAR USE, SOUTH COAST AIR BASIN

(Source: Task Report 7, Tables 3.10, 3.12, 3.15)

		Ratio of Pollutants With and Without Electric Cars				
Year	Percent Electric Car Use	Ozone*	NO_2*	CO**	SO_2**	Particulates**
1980	20	0.99/0.94	0.92/0.97	0.86	1.07	0.96
1990	80	0.90/0.88	0.86/0.99	0.74	1.14	0.79
2000	100	0.87/0.84	0.88/0.88	0.67	1.07	0.80
1980D	20	1.04/0.94	0.92/0.93	0.86	1.07	0.96

---

*(DIFKIN result)/(Rollback result).

**Rollback result.

Because Los Angeles is atypical in its meteorology and photochemistry, the air quality projections of Tables 4.7 and 4.8 are inapplicable to most other large US urban areas. The emissions projections, however, exhibit an underlying condition for air quality which may be expected elsewhere: rapid reductions in both the overall quantity of air pollutant emissions and the relative importance of automotive emissions. These are simply the developing impacts of the Clean Air Act of 1970, which adopted as a national goal the elimination of 90% of conventional automobile emissions by 1977.

5 ENERGY IMPACTS

5.1 BACKGROUND

Because future energy supply and demand has been repeatedly analyzed in recent years, existing studies and projections were relied upon here as much as possible. The 1972 report on the US energy outlook by the National Petroleum Council was employed as background. Recent studies of the California situation by Stanford Research Institute (SRI) and the RAND Corporation supplied the regional setting. Detailed projections and plans by the electric utilities serving the South Coast Air Basin provided local detail.

The future energy situation assumed in the baseline projections resembles the second of four alternatives detailed by the National Petroleum Council. It is characterized by rapid future growth in nuclear power generation, oil importation near present levels through the 1970s, and eventual independence of oil importation in the late 1980s. As noted in Sec. 2, the baseline transportation projections of this study include rising automobile efficiency and consequent moderation in gasoline consumption. Reasonably stable gasoline prices are assumed, in the range of 50¢ to 80¢ per gallon (in 1973 dollars, including taxes). This assumption, of course, is very uncertain, since world oil prices are now set by an international cartel.

5.2 ELECTRIC ENERGY BASELINE

In line with RAND, SRI, and utility forecasts of baseline growth in per capita energy consumption, Fig. 5.1 shows the electric energy consumption baseline projected for the South Coast Air Basin. The growth rate, about 4-1/2% per year, is considerably less than in the past, but the total increase projected from 1970 to 2000 is nevertheless about 300%.

The baseline electrical generating capacity is projected in Fig. 5.2. In the near term, it follows the facilities plans of Air Basin utilities:

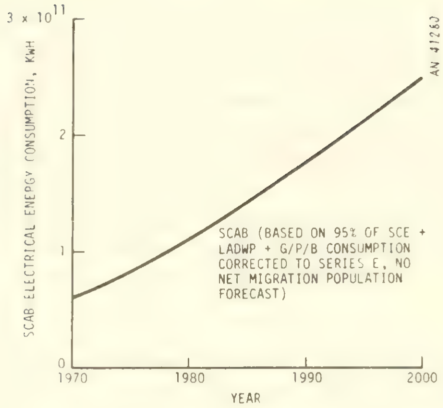


Figure 5.1. Projected Baseline Energy Consumption, South Coast Air Basin (Source: Task Report 5, Fig. 3.8)

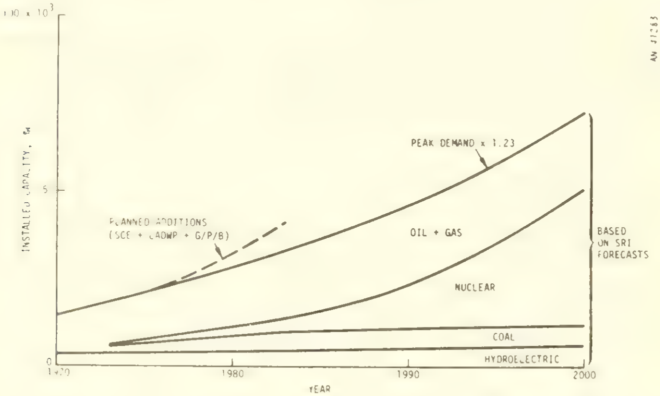


Figure 5.2. Projected Electrical Generating Capacity, South Coast Air Basin (Source: Task Report 5, Fig. 3.11)

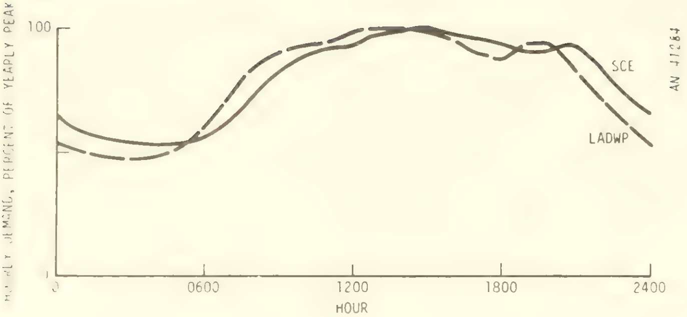
Southern California Edison (SCE), Los Angeles Department of Water and Power (LADWP), and the Municipal Utilities of Glendale, Burbank, and Pasadena (G/B/P). After 1978, however, these plans (though now lagging behind schedule) call for faster growth than is needed to meet the demand forecast of Fig. 5.1. Accordingly, the projection for later years in Fig. 5.2 is simply taken as 1.23 times the peak demand projection. The factor 1.23 allows 18.6% reserve capacity at peak load, a figure projected by SRI as appropriate for scheduled maintenance and a margin of safety.

Figure 5.3 shows recent hourly demand profiles for SCE and LADWP, which provide around 95% of the Air Basin's electricity. They are in reasonable agreement, both peaking with air conditioner demand on summer afternoons; even on the peak day, demand drops to about half the afternoon maximum after midnight.

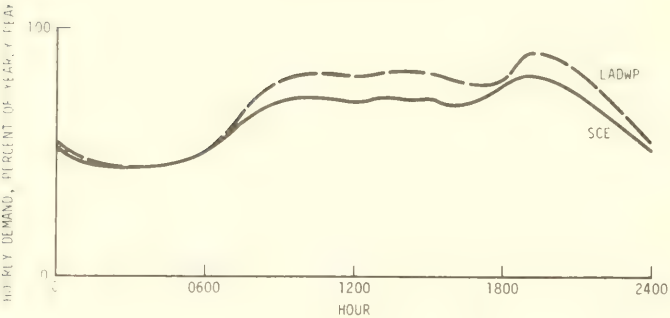
Baseline projections of peak-day and average-day supply and demand profiles for electric power in the South Coast Air Basin are shown in Fig. 5.4. These projections assume the overall demand growth of Fig. 5.1, the daily fluctuation of Fig. 5.3, and the availability of power from different sources of Fig. 5.2. They further assume that base loads will be taken over by future nuclear and coal power stations, leaving the higher-cost oil-fired power generation to be used increasingly for meeting peak loads.

All these assumptions are uncertain at best. The overall energy situation, and the particular future of electric power generation for Southern California, are both areas in which alternatives are under intense debate and future courses of action have not yet clearly emerged.

The demand fluctuations of Fig. 5.3 may be inapplicable in the future for several reasons. On the one hand, changed rate structures to encourage off-peak use or to discourage peak use could flatten the profile substantially. On the other hand, rising rates may decrease overall

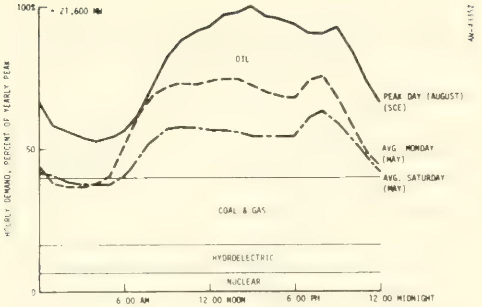


a) Typical Peak Month

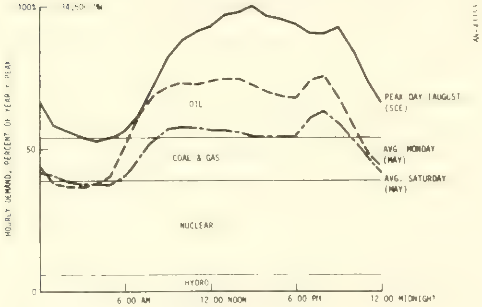


b) Typical Off-Peak Month

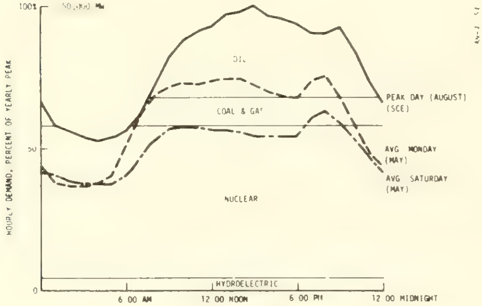
Figure 5.3. Variation in Hourly Electric Power Demand, 1973 (Source: Task Report 5, Fig. 3.12)



a) 1980



b) 1990



c) 2000

Figure 5.4. Profile of Hourly Electric Power Demands with Projected Supply, South Coast Air Basin (Source: Task Report 5, Fig. 3.13)

consumption without much depressing peak demands, as for air conditioning on very hot afternoons, and consequently exaggerate the daily variation in demand.

On the supply side in Fig. 5.4, there are also important uncertainties. The plans of regional utilities to build nuclear plants have not yet received all necessary permits and approvals, and intense debate over public safety and environmental pollution continues. Systematic conversion of oil-fired plants to coal could be required as a matter of national policy. Finally, if electric storage batteries are sufficiently improved, energy stored during early morning hours could be used to meet peak demands of the afternoon; substantially less generating capacity would then suffice, allowing the construction of less new capacity, whether nuclear or other, or earlier retirement of existing oil-fired facilities, or some combination of the two.

Given the projections of Figs. 5.4, considerable reserve capacity will be available even on the peak-demand day during the early morning hours. This capacity could be used for electric car recharge; if it were, oil would be the additional fuel principally consumed on the peak day in 1980 and 1990. The capacity potentially available for electric car recharge is shown in Fig. 5.5. The unused generating capacity is assumed to be as shown in Fig. 5.4, with recharge done late at night and in the early morning hours, and total demand including recharging limited to 85% of the annual peak so as to provide for necessary maintenance. On the average day rather than the peak day, much more power would be available. Also shown in Fig. 5.5 are the recharge requirements for 100% electric car use, given the baseline auto mileage projections of Sec. 3 and each of the per-mile electric car energy requirements of Sec. 2.

Even at rapid rates of electric car introduction, as will be discussed in Sec. 8, it appears unlikely that the required recharge power would exceed the available generating capacity projected, even for the peak day of the year. Thus generating capacity for recharge poses no limitations

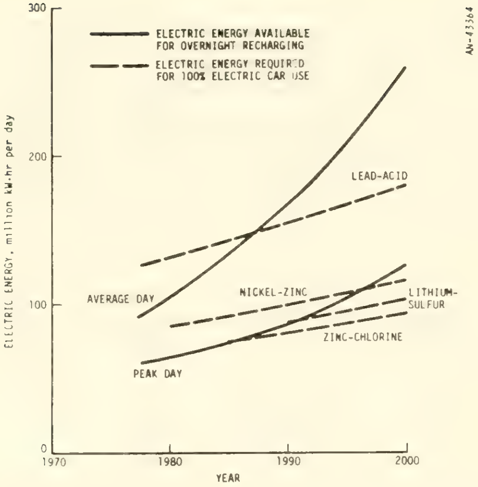


Figure 5.5. Projected Electric Car Recharge Energy, South Coast Air Basin (Sources: See Text)

on electric car use--unless, of course, baseline electric energy projections are not fulfilled. This might come about if advocates of reduced growth, environmental protection, neighborhood preservation, or nuclear safety prevail in legislative and judicial proceedings over utility plant expansion. It might also come about if rapid advances in battery technology permit utilities to store substantial quantities of electricity economically, allowing sizing of their generating facilities for average rather than peak loads. In this instance utilities might be expected to build additional new facilities only as required to serve electric cars (unless restrained by the forces just noted); if these new facilities were nuclear, then electric car use even on the peak day would not require petroleum fuels.

5.3 ENERGY IMPACTS

The energy consumption of prospective conventional and electric cars in the South Coast Air Basin is shown in Fig. 5.6. The average ICE car is expected to become much more efficient in its fuel usage, as discussed in Sec. 3. Energy usage for ICE cars in Fig. 5.6 includes a 10% penalty for refining energy in excess of that required in the production of power plant fuels from crude oil. Energy usages for electric cars in Fig. 5.6 assume a power plant efficiency of 36% (9500 Btu/kWh), and 91% transmission efficiency, as projected by SCE.

Overall, advancing battery technology promises to keep electric cars a bit ahead of the advancing efficiency of the average ICE car. It must be noted, however, that the electric cars are all low-performance subcompacts, in contrast to the larger "average" ICE car. In comparison with ICE subcompacts, as represented by the current Pinto and Honda in Fig. 5.6, the lead-acid battery car is relatively inefficient, and the advanced battery cars offer modest improvements which may well be matched by engineering progress in ICE subcompacts. The Pinto was the best selling subcompact in the Los Angeles region in 1973; the Honda led all subcompacts in fuel economy as measured by EPA for 1974 models.

In comparison with the average ICE car of Fig. 5.6, electric cars would offer some saving in petroleum use even if recharging were entirely dependent on petroleum-fired electric power generation. Under the baseline projections of this study, however, energy sources other than petroleum will become available for at least a portion of overnight recharging on the average day, as shown in Fig. 5.4. In consequence, usage of electric cars instead of average ICE cars would reduce petroleum consumption considerably more than Fig. 5.6 alone would imply. This is illustrated in Fig. 5.7, which shows savings in petroleum use for automotive travel as a function of percentage auto travel by electric cars, for each electric car characterized in Sec. 2. The "typical" weekday of Fig. 5.7 is a composite of typical weekdays for all 12 months of the year; thus the

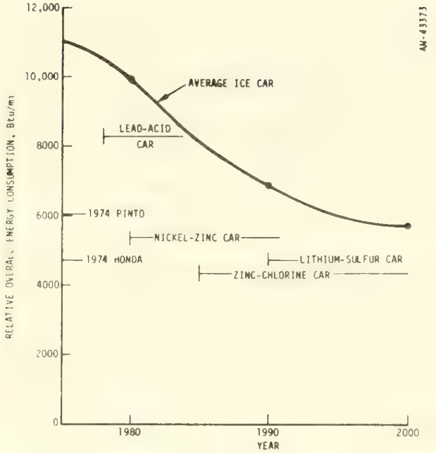


Figure 5.6. Comparative Auto Energy Consumption (Sources: Task Report 8, Tables 2.1 and 2.2; EPA 1974 Fuel Economy Measurements)

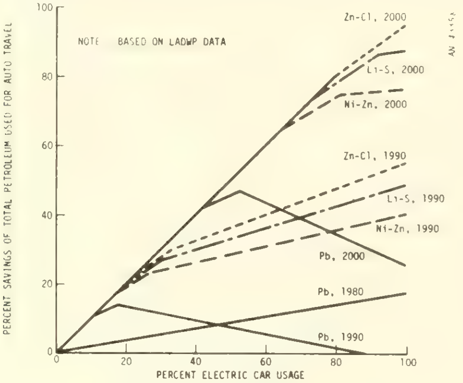
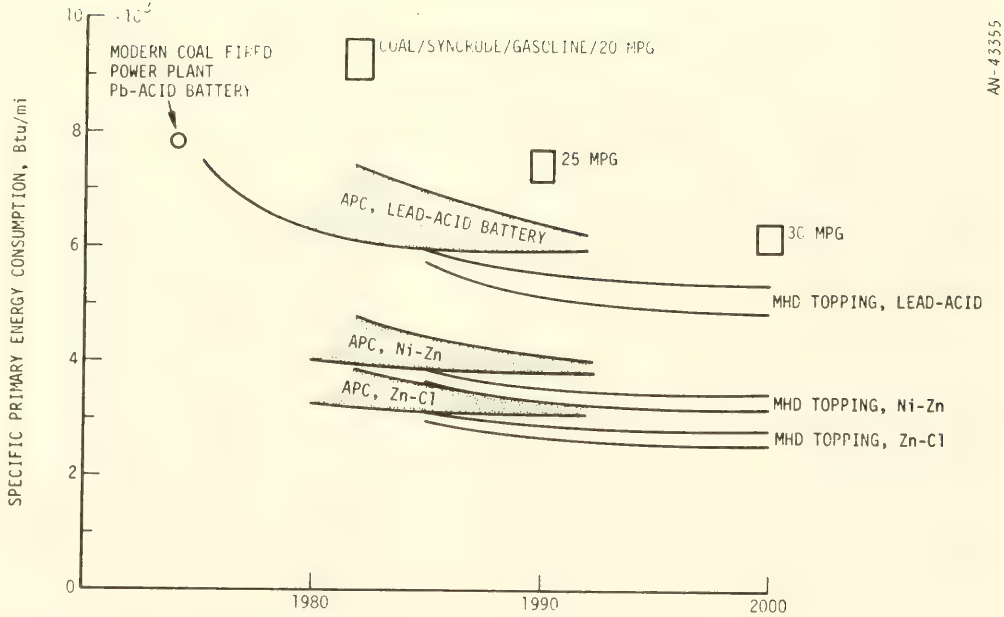


Figure 5.7. Petroleum Savings as a Function of Electric Car Usage, South Coast Air Basin (Source: Task Report 8, Fig. 2.7)

savings it shows in petroleum use are approximately those which could be achieved during a full year of electric car use. In general, low usage of electric cars can be almost entirely accomplished with recharge from nuclear power in 1990, so that initial petroleum savings are proportional to electric car use. At higher levels, where oil-fired recharge power is required, electric cars produce further saving on account of their greater overall fuel economy (compared to the "average" ICE car), but the rate of increase with electric car use is much less rapid.

At very high levels of use, electric cars must replace average ICE cars, as assumed throughout in Fig. 5.7. At low levels of use, however, electric cars might replace only subcompacts, in which case petroleum savings would be much less. On the other hand, the baseline projection of fuel economy for the average ICE car could prove overoptimistic, in which case savings due to electric car use could be significantly increased at every usage level.

In the baseline projections, relatively little additional generation of electric power from coal is included. Much-increased dependence on coal, however, is an important possibility in the US, not just for electric power generation, but also for production of synthetic crude oil and gasoline for automotive propulsion. In both these applications, important technological advances are likely: production of gasoline from coal itself is a significant technological innovation, while Advanced Power Cycles are being developed for improved efficiency of coal use in electric power generation. Some of these prospects are illustrated in Fig. 5.8, which compares the energy content of coal which would be required in various future years for automotive transportation by ICE cars and electric cars. While there are many uncertainties, it appears that as much as 50% less coal could be required in future years to propel electric rather than ICE cars.



APC = COAL/GAS/BRAYTON/RANKINE
MHD TOPPING = COAL/MHD/RANKINE

Figure 5.8. Comparison of Alternative Uses of Coal for Automotive Transportation (Source: Task Report 8, Fig. 2.1)

6 RESOURCE IMPACTS

Requirements of copper, steel, plastics, and other common materials for the electric cars of Sec. 2, without batteries, are modest in relation to overall US demand. At present auto sales rates in the South Coast Air Basin, for example, 100% substitution of the electric cars of Sec. 2 for conventional new cars would increase US copper demand less than 1%. The batteries of the electric cars, however, require various less-common materials; the amounts necessary could potentially impact US markets substantially, or even exceed domestic reserves.

Table 6.1 summarizes the resource impacts of key battery materials for maintaining large numbers of cars in the Los Angeles region. As indications of material availability, Table 6.1 shows US primary production and demand in 1968 and as projected to the year 2000, both from US Bureau of Mines data published in 1970. Electric car requirements are stated in terms of annual need for maintaining a given level of electric car usage, as opposed to building up the electric car population and its battery material inventory. Finally, significant impacts are noted, where they occur, for possible usage of electric cars both in the South Coast Air Basin and nationwide.

Comparison of the production and demand columns of Table 6.1 to the annual requirement column shows the prospective overall level of market impact, and the extent to which imports, foreign dependence, and foreign payments would be involved. Where electric car requirements are a small fraction of US primary production--that is, production exclusive of recycling--imports would be unnecessary. Where the electric car requirements are large compared to US primary demand, the major impact would probably be to increase imports. In the particular case of titanium, present production of titanium metal is near zero, and US demand is quite small. Production of and demand for titanium compounds, however, is very much larger. Table 6.1 shows the titanium content of such compounds, on the assumption that extraction of the metal could and would be undertaken to fulfill electric car demand.

TABLE 6.1

BATTERY MATERIAL PRODUCTION AND CONSUMPTION

(Source: Task Report 8, Table 3.5)

		Quantities, Thousands of Tons per Year						Significant Impact[**]	
		US Primary Production		US Primary Demand					
Battery Type	Material	1968	2000 (Range)	1968	2000 (Range)	Annual Electric Car Consumption,[*] South Coast Air Basin	Percent Electric Car Use Assumed, for Future Year	South Coast Air Basin Implementation	Nationwide Implementation[**]
Lead-Acid	Lead	354	520-1,120	880	1,300-2,800	22	17%, 1980		X
	Antimony	1.9	2.5-4.8	21.1	28-52	0.6	17%, 1980		X
Nickel-Zinc	Nickel	15	36-52	160	382-550	29	46%, 1990		X
	Zinc	529	786-1,500	1,406	2,040-4,000	20	46%, 1990		
Zinc-Chlorine	Zinc	529	786-1,500	1,406	2,040-4,000	12	100%, 2000		
	Titanium (Metal)	305 (0)	670-1,610 (0)	440 (13)	960-2,160 (62-234)	9.5	100%, 2000		X[††]
	Chlorine	8,400	26,400-43,900	8,400	26,400-43,900	130[+]	100%, 2000		
Lithium-Sulfur	Lithium	2.9	9.4-14.4	2.6	8.7-13.1	3.2	100%, 2000	X[††]	X[††]
	Graphite	3.0	4.0-4.7	60	80-135	50[+]	100%, 2000	X	X
	Sulfur	11,000	28,000-45,000	10,000	26,000-41,500	128[+]	100%, 2000		

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[*] Assume constant electric car population, 2-year battery life, and 90% material recycling. This does not include inventory buildup in cars on the road.

[**] Significant impacts are assumed wherever annual materials requirements exceed 20% of US primary demand for that year, as determined by linear interpolation between the 1968 demand and the midpoint of the range projected for 2000. National requirements for materials are assumed to be 20 times those for the South Coast Air Basin.

[+] No recycling assumed for this material.

[††] Electric car requirements for these materials would impact on production capacity for metallic forms.

The annual requirement column of Table 6.1 assumes the usage of electric cars tabulated in the adjacent column, with two-year battery life and 90% recycling of battery materials. A two-year life is relatively brief, even for lead-acid batteries, and tends if anything to overestimate the amount of battery material to be replaced each year. 90% recycling is the figure currently indicated for lead (in lead-acid battery data from the Battery Council International), and may also lead to overstatement of material requirements. The batteries required by the electric cars described in Sec. 2 are much more valuable than conventional auto batteries as salvage; recycling rates would tend to increase as a result. Again, the effect is to make the annual requirement of Table 6.1 conservatively large.

The maximum likely usage of lead-acid electric cars, as shown in Sec. 8, is for 17% of Los Angeles area travel in 1980. The resultant lead and antimony requirements are well under 10% of 1968 US primary demand, and hence not deemed likely to produce significant impacts. Nationwide, however, a 17% population of such cars would require 20 times the quantities of materials in Table 6.1; and this would clearly impact the metal market significantly.

Though nickel is a relatively scarce material, nickel for nickel-zinc batteries would not significantly impact the national market if electric car usage in Los Angeles reached the 46% level in 1990, the maximum foreseen in Sec. 8; but at 100% usage it would approach the significance threshold adopted in Table 6.1. The US is highly dependent on nickel imports; at $2 a pound, 29,000 tons of nickel imported per year would cost over a hundred million dollars and alter the US balance of payments accordingly.

The material requirements of the zinc-chlorine battery are relatively moderate, even for 100% usage in the Los Angeles area. For national implementation at the 100% level, however, the titanium (compound) market would be significantly perturbed.

The lithium required for lithium-sulfur batteries could impact national markets significantly, even for electric car usage only in Los Angeles. The present production of lithium is quite low, apparently because demand is low, and it is interesting to note that the US has been an exporter of the metal. Because production is quite small, it could probably be expanded to cope with electric car needs for Los Angeles, but national needs would be much more difficult. The US demand for graphite could be nearly doubled by demands for these batteries in the Los Angeles area alone. Graphite, however, is relatively inexpensive (around 10¢ a pound, in comparison with some $10 a pound for lithium), and world production would probably expand rapidly to meet such a demand increase.

Given the two-year battery life and 90% recycling of Table 6.1, the annual requirement listed is 5% of the total material inventory in battery cars. A buildup of this inventory over twenty years would annually require as much as the tabulated maintenance requirements in Table 6.1. Thus, to arrive at the steady-state conditions discussed so far would increase the tabulated requirements over a twenty-year period by a factor rising from one to two.

Another view of the materials inventories required in electric car batteries is presented in Table 6.2. This table shows US and world reserves, according to Bureau of Mines estimates, for important battery materials, and also the inventories of battery materials required for electrification of all Los Angeles automobiles and all US automobiles. Generally, world reserves are large in comparison with tabulated requirements for the Los Angeles region. For full national use of electric cars, however, even world reserves would be seriously impacted: "rolling" inventories of lead, antimony, lithium, nickel, and zinc in such electric car usage would amount to between 22 and 72% of tabulated world reserves.

TABLE 6.2

MATERIAL RESERVES AND REQUIREMENTS

(Source: Task Report 8, Table 3.6)

	Estimated Reserves, Thousands of Short Tons		Maximum Inventory Required for 100% Electric Car Use in 2000	
	US	World	South Coast Air Basin	United States*
Lead	39,000	99,000	3,550	71,000
Antimony	110	4,000	91	1,820
Nickel	900	>75,000	1,360	27,200
Zinc	78,000	90,000	1,000**	20,000**
Titanium	25,250	160,000	188	3,760
Lithium	5,254	6,036	64	1,280
Graphite	600	~100,000	106	2,120

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*Assumes national requirement is 20 times that of South Coast Air Basin alone.

**Determined by nickel-zinc battery car; requirements for zinc-chlorine battery are about 24% of these amounts.

Generally, of course, it must be recognized that reserves are calculated on the basis of known deposits from which materials may be extracted at specified prices, usually near those prevalent at the time of the estimate. New discoveries of mineral deposits, new production technology, and increases in materials prices can all cause reserve estimates to increase significantly. Recent major increases in nickel prices, for example, have made extraction from laterite deposits profitable, warranting major additions to the reserves shown in Table 6.2.

7 ECONOMIC IMPACTS

7.1 IMPACT ON TRANSPORTATION CONSUMERS

For the consumer, the electric car will be important in its direct impacts on the costs of automotive travel. Prospective costs for the electric cars characterized in Sec. 2 are summarized in Table 7.1, together with baseline cost projections for both subcompact and standard ICE cars.

Table 7.1 generally follows the format of the annual DOT publication Cost of Operating an Automobile, from which the ICE costs were primarily derived. To this format, in the last two lines of Table 7.1, are appended financing charges and total costs which include them. Financing charges were computed as though purchase costs of cars and propulsion batteries were amortized in equal payments throughout their lifetimes, at a 10% annual rate of interest. This rate is a compromise between the higher interest charges customary in auto financing, and the lower interest income that consumers forego on the equity they have in a car. The financing charge is necessary to reflect the considerably higher average investment which consumers must eventually support in electric cars.

For the ICE cars of Table 7.1, recent DOT figures are modified in two respects. First, additional initial and recurrent costs of antipollution devices are added in accord with estimates developed by the Environmental Protection Agency. Second, gasoline and oil prices are adjusted upward to the range of 50-80¢ per gallon for gasoline, as is projected to prevail (in 1973 dollars) through the study period. It should be noted that the DOT fuel economy figures were not modified; thus the major improvements projected in Fig. 3.5 are not reflected in Table 7.1. For the average Los Angeles car, these improvements could reduce fuel costs by about two-thirds of a cent per mile in the year 2000.

For the electric cars of Table 7.1, a 20% longer life was assumed than used by DOT for ICE cars. Considering the probable long life of

TABLE 7.1

PROJECTED LIFE-CYCLE CAR COSTS

1973 Dollars

(Source: Task Report 9, Tables 2.1, 2.3, 2.4)

Cost Item	ICE Cars*		Battery-Electric Cars**			
	Subcompact	Standard	Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur
Depreciation						
Basic Vehicle	$2,270	$4,817	$2,977	$ 2,945	$ 2,891	$ 2,795
Propulsion Battery and Replacements	0	0	4,200-10,982	6,125	993	1,440-2,400
Repairs and Maintenance	1,953	2,362	1,200	900	900	900
Replacement Tires	344	440	527	451	451	451
Accessories	57	57	69	69	69	69
Pollution Control	860	930	0	0	0	0
Gasoline and Oil***	2,004-3,484	3,097-5,395	0	0	0	0
Electricity	0	0	1,800	1,163	935	1,026
Insurance	1,376	1,485	1,782	1,782	1,782	1,782
Garaging, Parking, Tolls, Etc.	1,990	1,990	2,388	2,388	2,388	2,388
Taxes	805	1,299	1,248	1,241	1,241	1,241
Financing Charge†	1,591	3,200	3,009-3,225	4,462	2,640	2,580-2,628
TOTAL	13,250-14,730	19,677-21,975	19,200-26,498	21,609	14,290	14,672-15,680
Total Average Cost per Mile	.133-.147	.197-.220	.16-.218	.180	.119	.122-.131

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*10-year, 100,000-mile life.

**12-year, 120,000-mile life.

***At gasoline prices per gallon of $.40-.70 (not including $.10 tax), with corresponding range for oil; 21.4 and 13.6 miles/gallon were assumed.

†Assumes amortization of car and propulsion battery purchase prices over respective lifetimes at 10% interest charges.

the electric car's motor and controller, and the enhanced car body life likely in the gentle climate of Los Angeles, even longer lifetimes are possible. The 20% increase of Table 7.1 assumes that lifetime will be limited by interior and exterior wear and tear, by technological obsolescence, and by style changes, which in combination will eventually lead consumers to prefer purchasing new cars to repairing and refurbishing old ones.

Electricity costs for electric car recharging were assumed to be 1.9¢ per kilowatt-hour in Table 7.1, near the average marginal rate for large residential users in a recent year. Higher rates may be coming, but their effects on total costs would be minor, since electricity amounts to less than 10% of the total electric car costs per mile in Table 7.1. Road user taxes in current amounts are assumed for both electric and ICE cars; they are included in a separate tax account rather than in fuel costs.

Like fuel costs, repair and maintenance costs for electric cars are expected to be substantially less per mile than for gasoline cars, as will be discussed in more detail in Sec. 7.2. For the next decade, however, total electric car costs promise to be near the cost of standard-size ICE cars, and substantially higher than for ICE subcompacts. This is a consequence of the large prospective depreciation and financing costs of lead-acid and nickel-zinc batteries.

In accord with Sec. 2, the high-energy lead-acid battery pack is expected to last roughly 1.3 to 3.4 years in automotive use. At a retail price of 80¢ a pound (including a 10% allowance for turn-in of the old battery), the battery pack will cost about $1,200 to replace. Even at the high usage of 10,000 miles per year, the resultant depreciation charges range from 3.5¢ to 9¢ per mile. As noted previously, the longer life and lower cost are probably optimistic.

Because of its more expensive materials and higher capability, the nickel-zinc battery pack will cost about $2,930 (or even more, if recent increases in nickel prices persist). At a life of 400 full discharges or proportionately more partial discharges (as described in Sec. 2), the total depreciation cost for this battery pack is near that of the longer-lived lead-acid battery pack in Table 7.1.

If the goals of their developers are met, the zinc-chlorine and lithium-sulfur batteries will relieve the depreciation cost problem and make electric subcompacts cost-competitive with ICE subcompacts. The developers expect an initial cost of only $600 for these batteries, which are considerably lighter than the lead-acid and nickel-zinc batteries. Life targets are 500 deep cycles and 3-5 years, respectively; but the likelihood of meeting these ambitious targets remains to be established by laboratory and in-the-field vehicular tests.

Average car costs in the Los Angeles area are between those of the standards and subcompacts of Table 7.1, and are expected to move lower as the proportion of subcompacts in the auto population increases to a projected maximum of 45% by 1990. Table 7.2 shows extra total costs of electric cars relative to these average ICE car costs, which are necessarily the proper basis for comparison if electric car usage levels are very high. At lower levels of electric car use, where primarily subcompacts would be replaced, extra total costs could be higher, as is also shown in Table 7.2.

7.2 IMPACTS ON TRANSPORTATION SUPPLIERS

Baseline Projections. The importance of auto-related economic activity in the South Coast Air Basin in 1971 is indicated in Table 7.3. About 3.5% of the area's economy is directly involved in supplying and supporting automotive transportation, but a larger fraction of the area's businesses are involved because of the large number of gasoline stations.

TABLE 7.2

EXTRA LIFE-CYCLE COSTS OF ELECTRIC CARS

(Source: Task Report 9, Table 2.5)

Electric Car Battery Type	Extra Life-Cycle Cost Per Mile* Relative to Average Los Angeles ICE Car	Extra Life-Cycle Cost Per Mile* Relative to Los Angeles ICE Subcompact
Lead-Acid	1% to 37%	20% to 63%
Nickel-Zinc	13%	35%
Zinc-Chlorine	-25%	-11%
Lithium-Sulfur	-15% to -21%	-2% to -8%

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*Assumes gasoline at 50¢ per gallon including tax in 1973 dollars.

Baseline total regional employment was projected for the study period as summarized in Table 7.4. Baseline activity in each of the industrial classifications of Table 7.3 was separately projected from historical trends. The auto-related employment thus determined is also shown in Table 7.4, as a percentage of total employment. This percentage grows slowly, primarily because of higher-than-average rates of employment growth in the auto distribution, supply, and repair sectors.

The employment in industries likely to be impacted by electric cars is relatively small. At under 4% of the total for the South Coast Air Basin, it stands well below current regional unemployment. Even if Los Angeles shifted entirely to electric cars in a period as short as ten years, the annual impact on regional employment would be very small. Within the individual industries of Table 7.3, however, electric car use would make major changes. As shown in Table 7.5, activity in several of these industries is highly dependent on the needs of automotive internal-combustion engine systems (including radiator, exhaust, fuel, and ignition subsystems)--needs unlikely to be paralleled in automotive electric motor

TABLE 7.3

RELATIVE IMPORTANCE OF AUTO-RELATED ACTIVITY, SOUTH COAST AIR BASIN (1971)

(Source: Task Report 4, Table 4.2)

	Employment	Percent of Area Total Employment	Payroll, $ million	Percent of Area Total Payroll	Number of Firms	Percent of Area Firms
Vehicle and Parts Mfg. (SIC 3717)	19,210	0.5	233.5	0.7	62	0.0
Petroleum--Wholesale and Retail Sales (SIC 5092 and 5541)	39,703	1.0	192.7	0.6	6,694	4.1
Auto Parts and Supplies (SIC 5013, 5014, and 5531)	22,606	0.6	175.4	0.6	1,938	1.2
Auto Repair (SIC 7534, 7538, and 7539)	9,448	0.2	65.0	0.2	2,444	1.5
Vehicle Distribution (SIC 5012)	5,606	0.1	57.2	0.2	147	0.1
Vehicle Sales (SIC 5511 and 5521)	37,679	0.9	362.2	1.2	1,182	0.7
Battery and Motor Mfg. (SIC 3621, 3622, and 3691)	4,910	0.1	44.5	0.1	65	0.1
		3.4		3.6		7.7

TABLE 7.4

BASELINE PROJECTIONS OF TOTAL AND AUTO-RELATED EMPLOYMENT, SOUTH COAST AIR BASIN

(Source: Task Report 4, Tables 2.1, 4.5-4.7)

Year	Total Projected Employment	Projected Auto-Related Employment, Percent of Total
1980	4,335,000	3.7%
1990	4,579,000	3.9%
2000	5,025,000	4.0%

TABLE 7.5

CURRENT PERCENT DEPENDENCE OF AUTO SUPPORT INDUSTRIES ON THE INTERNAL COMBUSTION ENGINE SYSTEM

(Source: Task Report 9, Tables 3.3, 3.5, 3.6)

Service Stations	91%
Auto Parts and Supplies	44%
Auto Repairs and Service	72%

systems. In battery manufacturing, however, the situation is reversed. These cases are discussed individually, in order of importance of employment impacts, in the remainder of this section. Section 7.3 discusses the collective impacts.

Impacts on the Petroleum Distribution Industry. According to recent figures for the South Coast Air Basin, over 82% of service station sales are concentrated in gasoline and oil. After allowance for additional ICE-related sales of parts and labor, only an estimated 9.2% of sales would remain if all ICE automobiles were replaced by electric cars. For lead-acid battery cars, the reduction is partly offset by new requirements for periodic inspection and addition of water to the individual cells of the batteries. 50% of motorists were assumed to service these batteries themselves, to save the expense and time of visiting a service station; nevertheless, the prospective reduction in baseline employment for wholesale and retail petroleum distribution is 71%, assuming 100% usage of lead-acid electric cars. Other battery cars utilize battery systems for which maintenance will be largely or entirely eliminated; the consequent impacts are even greater than for lead-acid battery cars.

Impacts on the Battery Manufacturing Industry. Because battery production can be economical on a relatively modest scale and because battery materials will be largely recycled, local manufacturing of batteries is projected for electric cars in the Los Angeles region. With high levels of electric car use, much of the decrease in service station employment will be compensated by an increase in battery manufacturing employment. Of the battery candidates, only lead-acid batteries are now in production; hence the estimates of employment requirements for manufacture of advanced batteries, which here were based on discussions with battery developers, are at best relatively uncertain. Moreover, battery production rates (and manufacturing employment) for a given level of electric car use will depend on battery lifetimes, which are also uncertain.

Impacts on the Automotive Aftermarket and Repair Industry. Elimination of ICE propulsion would eliminate 44% of current sales of automotive aftermarket items, according to Table 7.5. To the remaining sales would then be added sales of replacement batteries for electric cars, which differ for each battery type depending on its prospective frequency of replacement. Except for the short-lived lead-acid batteries, however, battery sales to electric cars would be less frequent than for the ICE cars they replaced. Each battery would, of course, be a much larger unit at a much higher price for the electric cars; but a much lower percentage markup and ratio of sales effort per sales dollar is expected.

Recent reports of frequencies of ICE car services, labor involved per service, and the resultant distribution of service labor indicate that over 50% of labor hours are involved in ICE engine overhaul and tuneup alone. In total, removal of the ICE system would eliminate about 72% of car service hours. Added service requirements of the electric power train are expected to be minimal: annual inspection of the controller and motor, with motor brush replacement as necessary. Battery service for electric cars was previously assumed to be performed at service stations, and is not included here.

7.3 OVERALL ECONOMIC IMPACT

Table 7.6 aggregates the impacts that were discussed individually in Sec. 7.2, plus small additional impacts expected in the new car sales industry. In every case, substantial reductions in total regional employment are the direct result of the assumed 100% usage of electric cars. Reductions in total area personal income are relatively less, however,

TABLE 7.6

DIRECT EFFECTS ON LOCAL IMPACTED INDUSTRY DUE TO 100% ELECTRIC CAR USE IN THE SOUTH COAST AIR BASIN

(Source: Task Report 9, Table 4.1)

		Total Direct Effects on Impacted Industries	
Year	Electric Car Battery Type	As Percent of Total Area Employment	As Percent of Area Personal Income
1980	Lead-Acid	-0.22 to -0.79	-0.23 to +0.14
1990	Lead-Acid	-0.17 to -0.74	-0.20 to +0.15
	Nickel-Zinc	-0.88	-0.18
	Zinc-Chlorine	-1.20	-0.36
2000	Zinc-Chlorine	-1.21	-0.31
	Lithium-Sulfur	-1.15 to -1.25	-0.27 to -0.31

largely due to a shift in employment from low-pay service station jobs to higher-pay battery manufacturing jobs, as shown in Table 7.7. In the case of the shortest-life lead-acid battery, regional personal income would actually increase due to this effect.

Although auto manufacturing activity in the South Coast Air Basin is almost entirely assembly, which would presumably continue with little change even though electric propulsion replaced ICE propulsion, outside the area there would be impacts felt due to wide use of electric cars in Los Angeles. These impacts would come about through reduction of ICE manufacturing and a corresponding increase in electric motor and control manufacturing. The ICE manufacturing reduction would be small compared to annual national fluctuations in the automotive business, however, and consequently minor in impact. The national impacts on electric motor and control manufacturing would range downward from 3.3% and must also be regarded as minor.

In the employment changes of Table 7.7, individuals losing service station jobs who could find new employment in battery manufacturing would benefit through a major increase in earnings. Such cases could be few,

TABLE 7.7

STRUCTURE OF EMPLOYMENT CHANGES IN THE SOUTH COAST AIR BASIN DUE TO 100% ELECTRIC CAR USE, 1990

(Source: Task Report 9, Table 4.2)

	Petroleum Distribution	Battery Manufacturing	Auto Parts and Service	Auto Sales
Electric Car Type:				
Lead-Acid	-32,400	14,800 to 39,200	-14,900 to -11,400	-3,450
Nickel-Zinc	-41,500	20,600	-15,800	-3,450
Zinc-Chlorine	-41,500	6,600	-16,800	-3,450
Lithium-Sulfur	-41,500	4,600 to 8,100	-18,600 to -14,600	-3,450

however, because many service station jobs require minimal skills and are often held by those unqualified for more demanding employment elsewhere.

Beyond the direct effects of Table 7.7, secondary and tertiary impacts on regional economic activity may be expected. For 100% use of lead-acid or nickel-zinc battery cars, total regional expenditure for auto transportation would increase significantly, while regional labor inputs to supply this transportation would generally decrease. The difference would be made up by expanded regional imports from the rest of the nation, with a corresponding reduction in regional funds available for purchase and import of other needed commodities and services. Such reductions tend to depress regional payrolls. Conversely, reduced regional expenditures for zinc-chlorine and lithium-sulfur battery cars could increase funds available for extra-regional purchases and thus tend to expand regional economic activity.

8 USAGE ANALYSIS

8.1 APPROACH

The competitive disadvantages of electric cars in the auto marketplace have long held their sales and usage to negligible levels. Air pollution and energy considerations external to free-market transactions, however, suggest that much higher electric car use might be beneficial overall in future years. In this section, specific higher levels of electric car sales and use are hypothesized, so that the desirability of the net impacts may be subsequently evaluated.

First, daily driving patterns in Los Angeles are analyzed to develop basic needed data: the extent to which limited-range cars are applicable to drivers' actual travel. Next a lower bound on future electric car use is developed by projecting free-market sales, and an upper bound is postulated from production lead-time considerations. Then intermediate usage levels are hypothesized as possible public policy goals, and measures required to achieve them are considered. Finally, specific schedules for introducing alternative electric cars are postulated, so that the net benefits of alternative future levels of use may be evaluated in Sec. 9.

In this analysis, as throughout this report, overnight recharging of electric car batteries is assumed. This assumption is important to usage for two reasons: first, because it implies that daily driving must be limited to the range between recharges; and second, because it also implies that availability of residential recharging facilities will be a prerequisite for electric car use.

To circumvent the range limitations of electric cars implicit in overnight recharging, systems of service stations are sometimes suggested to make available interchangeable battery packs. Such stations would maintain large inventories of battery packs on recharge, substituting fully charged for discharged packs with results equivalent to refilling the gasoline tanks of conventional cars. In any large-scale, long-term usage of electric cars with very limited range, such institutional arrangements would surely develop to supplement overnight recharging, despite the considerable associated cost. In this study, however, such prospects are not considered further, simply because improved technology, improved range capability, and therefore reduced need for battery exchange appear less than ten years away. Within that limited time, the wide development of a battery exchange system seems unlikely.

Overnight recharging of electric car batteries requires considerable amounts of electricity. At the energy consumption rates of Table 2.2, recharge energy for the average day's driving of 30 miles will range from about 12 to 24 kWh. Corresponding average recharge power levels during 8 hours are 1.5 to 3 kW. Initial recharge rates may be twice the average rates, however, so 3 to 6 kW may initially be desirable; on days of more than average driving, further increases in charging power will be required. In comparison, the standard 110-V, 15 amp AC outlet delivers 1.65 kW maximum. Evidently, then, 220-volt circuits capable of delivering 5 to 10 kW will be required for overnight recharge, and electric cars will be unattractive or infeasible for those who cannot conveniently arrange such electrical service at their car's overnight parking place.

8.2 APPLICABILITY OF LIMITED-RANGE ELECTRIC CARS

The lead-acid battery car of Sec. 2 is capable of some 55 miles of urban driving between recharges, considerably more than the 30 miles driven each day by the average urban motorist. Nevertheless, the electric car is not necessarily adequate for the average motorist, because he will occasionally wish to drive further than its range capability--even if the capability is increased far above 55 miles. The adequacy and applicability of the electric car must consequently be measured in terms of the fraction of days on which its range would probably satisfy typical driving requirements.

In this study, an electric car range adequate for 95% of urban driving days was employed as the criterion of electric car applicability. Less than a 5% sacrifice in desired urban travel is implied by this criterion, since even on problem days the electric car could provide at least a part of the desired mileage. Interurban travel is assumed here to be made by other means.

Though urban driver travel has been repeatedly surveyed in origin-destination studies across the nation, the basic analytic unit has been the single trip. This unit, unfortunately, is inadequate for the present purpose. To determine the probability that the average driver will wish to drive more than a specified range on an average day, the distribution of total trip mileages for driving days must be determined. To do so, computer tapes were obtained from the Los Angeles Regional Transportation Study detailing 197,000 trips described at 33,000 households (a 1% sample) in the 1967 origin-destination survey. A special processing program then computed and totaled mileages of trips reported by each surveyed driver for the survey day, and from these whole-day mileages developed distributions of daily driver travel.

The resultant distributions of urban travel distance on the survey day are shown in Fig. 8.1, together with the ranges selected for lead-acid and advanced battery cars. Among drivers with cars available on the survey day--that is, drivers from households reporting as many available vehicles as drivers--83% drove less than the range of the lead-acid battery cars, while 98.4% drove less than the range of the advanced battery cars. Where a single car served the needs of two drivers, the corresponding figures were lower: 55% and 95%. Since the survey disclosed that 88% of drivers had cars available, and in future years even higher automobile ownership is predicted, the upper distribution of Fig. 8.1 has been taken to define electric car applicability, rather than the more demanding lower distribution for single cars serving two drivers.

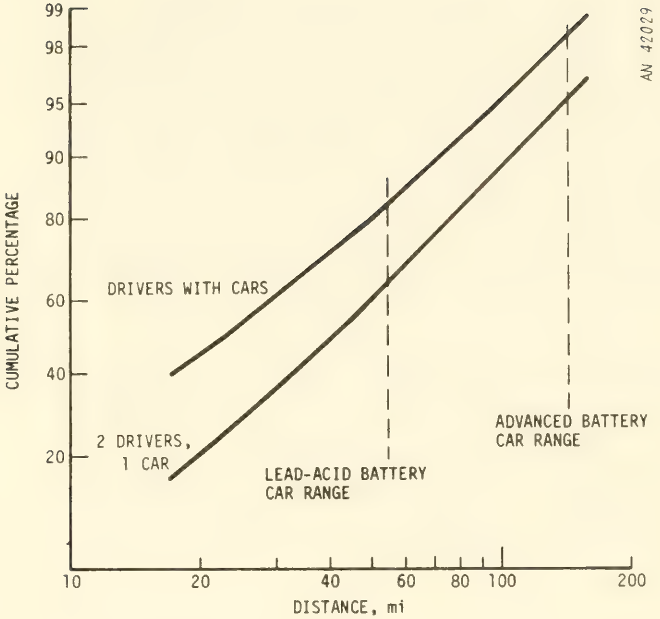

Figure 8.1. Adjusted Distributions of Daily Travel, Los Angeles Region, 1967 (Source: Task Report 10, Fig. 4.2)

Though the advanced battery-car range is generally applicable to drivers' needs by the criterion of this study (even for cars shared by two drivers), the lead-acid battery car is not. It could be satisfactory, however, in restricted circumstances. Figure 8.2 shows daily driving range distributions for secondary drivers in multicar households, computed from the basic results of Fig. 8.1 under the assumption that separate travel of individual drivers in households is uncorrelated (i.e., that two drivers in a household will not tend to plan separate long trips for the same days). The figure shows that the lead-acid battery car would be applicable to 96.6% of secondary-driver days in two-car households, where the secondary driver is defined as that driver traveling least on the given day.

For electric cars to be useful, overnight recharging facilities must be made available. This will generally require a 220-volt electric outlet near the car's parking place. Such outlets are not always feasible: according to the 1967 survey, only 74% of Los Angeles area cars had off-street overnight parking available. Furthermore, some of this off-street parking was in apartment lots or garages in which electric installations would be more difficult to arrange than at single-family houses, where the householder is in control and often has both 220-volt service and a private garage.

89% of single-family housing units reported having off-street parking in the survey, and were assumed to be able to provide recharge facilities for electric cars in 1980. 1,136,000 single-family households in the Los Angeles area are expected to have more than one car by 1980; at 89% of these, or 1,011,000 households, the lead-acid electric car might reasonably replace a conventional secondary car. In 1990, advanced battery cars with sufficient range for general use might reasonably replace all cars having off-street parking at single-family housing units. Of 4,188,000 cars expected at single-family housing units, at least 74%, or 3,099,000, should have off-street parking. By 2000, when electric cars might be in more general use, recharge provisions might be assumed available at off-street parking of all residences, that is, for 74% of all cars in the region, or 5,624,000 cars.

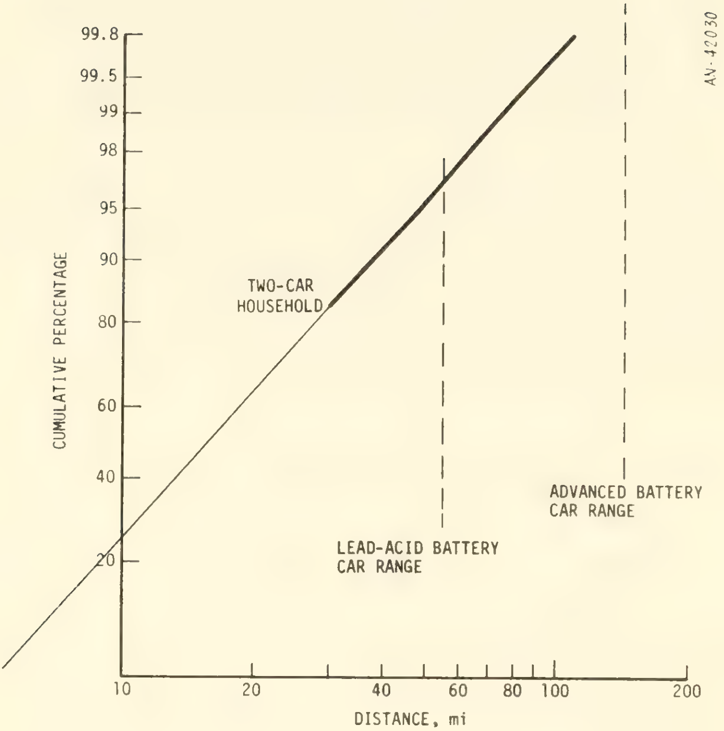

Figure 8.2. Probability of Daily Driving Less than a Given Distance for Secondary Drivers with Cars (Source: Task Report 10, Fig. 5.1)

These projections of candidates for electric car replacement in future years are shown in Table 8.1. For 1980, the candidates constitute 17% of all cars but account for only 11% of daily vehicle miles. This arises in the limited daily range and usage of secondary cars, which would be driven only 6400 miles per year rather than the usual 10,000 miles.

The numbers of candidate cars in Table 8.1 are plainly impressive. Even with the limited 55-mile range assumed for electric cars with lead-acid battery technology, over a million conventional cars could be replaced in the Los Angeles region with very little sacrifice of daily urban travel. Since driving in Los Angeles appears similar to that elsewhere in the nation, prospects are that electric cars could find comparably wide application on a national basis.

TABLE 8.1

CANDIDATES FOR ELECTRIC CAR REPLACEMENT, SOUTH COAST AIR BASIN
Source: Task Report 10, Table 5.4

	1980	1990	2000
Cars, thousands	1,011	3,099	5,624
Percent of Total	17	46	74
Daily Vehicle Miles, millions	18	90	169
Percent of Total	11	46	74

8.3 ALTERNATIVE USAGE LEVELS

Prospective free-market sales and use of electric cars place a lower bound on their usage and consequent impact. Recent electric car market studies based on consumer interviews, for example, projected that only 1 to 2% of national car sales would be captured by electric cars in 1980.*

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*See Task Report 10, Sec. 6.3.

In a free-market projection for the Los Angeles region undertaken for this study, a review of price, performance, and market share data for subcompact ICE car sales in the Los Angeles area disclosed no useful quantitative relationships for projecting electric car sales. Instead, the data show that wide differences in market shares of competing conventional cars are occasioned by differences in price, performance, and style which are insignificant in comparison with the differences between ICE and electric cars. In short, there is no basis in current market share data for quantitative forecasting of electric car sales. On the other hand, the data do not show that electric cars cannot sell well: an ICE car with novel propulsion (the Mazda) captured a substantial market share despite a significantly higher price, and low-performance cars such as Volkswagen successfully competed despite power-to-weight ratios as low as those of the electric cars characterized in Sec. 2.

Since quantitative projection methods for electric car sales forecasts were not developed in this study, a qualitative approach was necessary. From qualitative consideration of the factors noted above, and from published electric car market surveys, the free-market sales of electric cars characterized in Sec. 2 were estimated by assuming capture rates of 5%, 10%, and 15% of sales to replace candidate cars for 1980, 1990, and 2000 in Table 8.1. The resultant electric car sales range from under 1% of the Los Angeles regional market in 1980 to 11.1% in 2000. The resultant regional populations of electric cars are at most a few percent. Thus the free-market case places a lower bound on electric car use which is small enough to promise little area-wide impact.

An upper bound on prospective electric car use, assuming that high usage levels were to be urgently fostered by public policy, is basically set by manufacturing lead times and acceptable scrappage rates for existing cars. Because transportation controls proposed for the Los Angeles area to assure compliance with the Clean Air Act of 1970 include drastic gasoline rationing, a high degree of urgency is implicit in public policy and hence seems appropriate in setting an upper bound on electric car use. Accordingly, the upper bound projection for electric car population is based on assumptions of an immediate decision to proceed (in 1975), a three-year lead time to production in 1978, and a production quantity to support sales amounting to 80% of projected sales for conventional cars in the Los Angeles region.

Figure 8.3 shows upper and lower bound electric car populations in future years which would result from the bounding sales projections. It also shows total regional car population (the baseline projection), and two intermediate electric car populations which could be adopted as public policy goals. The "high use" policy projection assumes auto market shares for electric cars proportional to the candidate percentages in the second

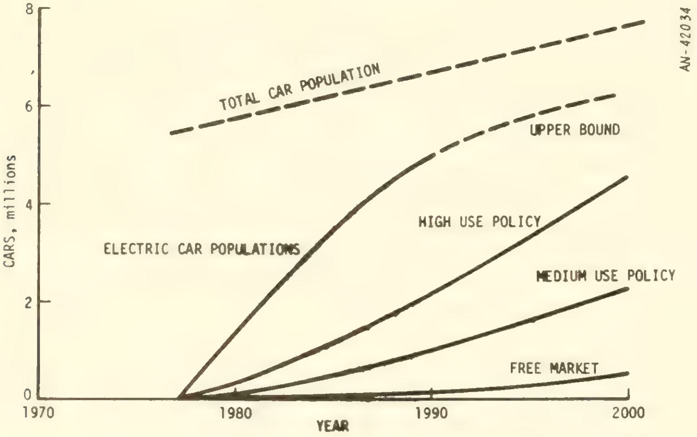

Figure 8.3. Alternative Electric Car Population Projections, South Coast Air Basin (Source: Task Report 10, Fig. 8.1)

line of Table 8.1, with linear interpolation between tabulated values, and sales beginning in 1978. The "moderate use" policy assumes electric car market shares half those for "high use."

On the one hand, the hypothetical policy goals of Fig. 8.3 are very high: they presume major changes in a major sector of the economy which are very unlikely under free-market conditions and consequently would require powerful legislation to be achieved. On the other hand, they are relatively low so far as auto impacts are concerned: even in 1990 they lead to electric car populations of less than 1 in 3, with correspondingly low leverage for the electric cars in changing regional conditions dependent on the automobile.

The probable difficulty in achieving high levels of electric car use may be appraised in terms of the relative costs of electric cars. Table 8.2 summarizes the extra initial and life costs of electric cars relative to competitive ICE subcompacts. Most of the initial cost differential is attributable to the battery; through battery leasing, this difference could be shifted to operating costs, so that the remaining extra initial cost might not be a substantial buyer deterrent, given the probable longer life and reduced maintenance of the electric car. The life cost differentials remain as shown, however, and for the lead-acid and nickel-zinc batteries they are high.

Table 8.2 shows these extra life costs both per mile and per 30-mile day, for which about a gallon of gasoline would be required to fuel the competitive ICE subcompact. If a gasoline tax were instituted to discourage the ICE subcompact by eliminating its cost advantage relative to lead-acid and nickel-zinc battery cars, per-gallon gasoline taxes of $0.81-2.55 would be required, as Table 8.2 indicates. Because of the additional performance disadvantages and range limitations of the electric cars, an even greater tax might actually be necessary to ensure their use. Any such taxes would be very painful and would inappropriately discourage total auto travel, so per-day subsidies of the electric cars

TABLE 8.2

EXTRA COSTS OF ELECTRIC CARS

Source: Task Report 10, Tables 8.2, 8.3, 8.4

Car Battery Type	Extra Initial Cost*		Extra Life-Cycle Cost*	
	Without Battery	With Battery	¢ Per Mile	$ Per 30-mile Day
Lead-Acid				
Best Life	$707	$1907	2.7¢	$ .81
Worst Life	707	1907	8.5	2.55
Nickel-Zinc	675	3615	4.7	1.41
Zinc-Chlorine	621	1221	-1.4	-.42
Lithium-Sulfur				
Best Life	525	1125	-1.1	-.33
Worst Life	525	1125	-.2	-.06

---

*In 1973 dollars, relative to ICE subcompact at $2270 initial cost and 13.3¢/mi operating cost (for 10,000 mi/yr and gasoline price of $.50 per gallon including taxes).

in like amounts could be preferable. In either case, heroic measures appear required to ensure substantial use of the higher-cost electric cars.

For the remaining battery cars of Table 8.2, lower total operating costs than those of conventional ICE subcompacts are indicated. Because of range and performance disadvantages, however, some sort of subsidy or differential taxation would probably be required to bring these cars into general use. Moreover, it should be noted that the cost differentials of Table 8.2 could disappear, or be reversed, if the cycle-life goals of the battery developers are not met.

To serve as a basis for overall impact evaluations and to permit clean differentiation between basic battery technologies, simple schedules were postulated for introduction of individual types of electric cars, in quantities which would permit achievement of the policy use levels of Fig. 8.3 through combinations of individual schedules. These schedules are shown in Table 8.3.

TABLE 8.3

BASIC SCHEDULES FOR ELECTRIC CAR INTRODUCTION
Source: Task Report 10, Table 8.5

Target Year	Use Policy	Elec. Car Pop. Target	Battery Type	Sales Period	Approx. Avg. Market Share
1980	High	5%	Lead-acid	1978-80	16%
1990	Moderate	15%	Lead-acid	1978-90	16%
			Nickel-zinc	1980-90	17%
			Zinc-chlorine	1985-90	30%
	High	30%	Nickel-zinc	1980-90	35%
2000	Moderate	30%	Zinc-chlorine	1990-2000	35%
			Lithium-sulfur	1990-2000	35%
	High	60%	Zinc-chlorine	1990-2000	70%
			Lithium-sulfur	1990-2000	70%

9 EVALUATION OF ALTERNATIVE USAGE LEVELS

In this section, the individual impacts analyzed in Secs. 4-7 are evaluated and summarized for the particular levels of electric car use hypothesized in Sec. 8. The impact valuations are then assessed in relative importance, so that the most desirable future levels of electric car use may be selected.

Table 9.1 summarizes the major quantitative impacts of the hypothesized levels of electric car use on air pollution, energy, and the economic situation in the Los Angeles region. It also includes subjective assessments of impacts on national markets for requisite battery materials, and the prospective degree of intervention required in the free market to bring about the indicated electric car use.

The air pollutants included in Table 9.1 (oxidant and sulfur dioxide) are the most important in the Los Angeles region among those for which national air quality standards have been promulgated: in the baseline case of this study, their concentrations are projected to remain in excess of the national standards even after expected major reductions. Ozone concentration changes in Table 9.1 were obtained from Table 4.8 for the given levels of use by simple linear interpolation. SO_2 concentration changes in Table 9.1 are expected to be near zero because the indicated usage levels require almost no petroleum-fired recharge, as Fig. 5.7 indicates, in every case but one. The exception, 30% usage of nickel-zinc battery cars in 1990, requires only about 10% of the petroleum-fired recharge energy implicit in the 80% usage level for 1990 of Table 4.8; accordingly, Table 9.1 shows a change in SO_2 level for this case which is only 10% of the figure in Table 4.8.

The petroleum use figures in Table 9.1 were taken from Fig. 5.7. Except for the lead-acid battery car cases and the case of 30% nickel-zinc battery car use in 1990, very little recharge power is expected to be generated by petroleum-fired power plants, so that the savings in automotive petroleum use are nearly equal to the fractional electric car use.

TABLE 9.1

IMPACTS OF ALTERNATIVE LEVELS OF USE OF ELECTRIC CARS IN THE LOS ANGELES REGION

(Sources: Tables 4.8, 6.1, 7.2, 7.6, 8.3; Fig. 5.7)

	Situation		Percentage Changes in Regional Baselines					Implementation Problems	
Year	Electric Car Use, Percent	Battery Type	Air Pollutant Worst-Case Concentrations		Auto Travel Petroleum Use	Auto Travel Cost	Direct Employment	Providing Incentives	Providing Resources
			Ozone	SO_2					
1980	5	Lead-Acid	0.0	.0	- 1	0.0 to 1.9	-0.01 to -0.04	Major	Minor
1990	15	Lead-Acid	-1.9	.0	-13	0.2 to 5.6	-0.03 to -0.11	Major	Minor
	15	Nickel-Zinc	-1.9	.0	-15	2.0	-0.13	Major	Minor
	15	Zinc-Chlorine	-1.9	.0	-15	-3.8	-0.18	Minor	Minor
	30	Nickel-Zinc	-3.8	1.4	-25	3.9	-0.26	Major	Moderate
2000	30	Zinc-Chlorine	-3.9	.0	-30	-7.5	-0.36	Minor	Minor
	30	Lithium-Sulfur	-3.9	.0	-30	-4.5 to -6.3	-0.34 to -0.38	Minor	Moderate
	60	Zinc-Chlorine	-7.8	.0	-60	-15.0	-0.73	Moderate	Minor
	60	Lithium-Sulfur	-7.8	.0	-60	-9.0 to -12.6	-0.69 to -0.75	Moderate	Moderate

These figures in Table 9.1 assume that electric cars replace average cars in Los Angeles; if electric cars instead replaced subcompacts, savings would be reduced correspondingly.

The auto travel costs in Table 9.1 were obtained by linear extrapolation from the relative costs of Table 7.2. It should be noted that cost changes are shown relative to the total for all auto travel, including both conventional and electric cars, again under the assumption that electrics replace average conventional cars. Depending on the methods used to encourage electric car use, cost increases or decreases may be spread over all auto travelers, or concentrated on electric car users. At the lower usage levels, it is possible for electric cars to replace only subcompacts, in which case the cost increases in Table 9.1 would be larger, and the cost decreases smaller.

The changes in regional transportation employment in Table 9.1 were obtained by linear interpolation for each usage level and year in Table 7.6. Employment changes overall are small relative to normal unemployment, and would develop slowly over periods of 5 to 10 years.

The evaluations of resource problems in Table 9.1 follow the judgments presented in Table 6.1. Impacts on US demand would be minor except in the case of high nickel-zinc battery car usage, where moderate increases in US imports would result, and in the case of the lithium-sulfur battery cars, where major expansion of facilities for production of lithium metal would be required.

Finally, the incentives problems noted in Table 9.1 were judged according to the extra dollar cost of particular electric cars, the extent to which their daily range is limited, and the level of use assumed. Where high costs and low daily ranges are involved and high levels of use are sought, implementation incentives pose more difficult problems.

Overall, loss of auto capability is probably the most important impact of electric cars not shown directly in Table 9.1. This loss--measured in terms of low acceleration, limited range, and small capacity relative to what conventional automobiles offer--would reduce opportunities now available to auto travelers more than it would actually curtail travel itself; opportunities, however, are often important considerations in consumer decisions and in benefits which must be imputed to resultant selections.

The most important potential benefit of electric car use shown in Table 9.1 is reduced petroleum consumption. The most important costs of electric car use are loss of auto capability and the expense, inequities, and rigidities of government intervention in free markets necessary to bring about the indicated levels of use. Both these costs are subsumed in the incentives problems assessments of Table 9.1, as are the extra dollar costs of lead-acid and nickel-zinc battery cars, which are also important.

Relative to these impacts, reductions in air pollution due to electric car use are unimportant. Even at the highest levels of use in Table 9.1, reductions in ozone concentration are small, and are not adequate to reach compliance with Federal standards. Impacts on employment are similarly small: the affected fractions of regional employment are much less than typical regional unemployment; furthermore, these impacts would appear gradually over a period of years. Materials resources for regional application could be provided with relatively little difficulty, and consequently pose no major barrier to implementation.

In this light, the basic issue in selecting the most desirable level of electric car use is whether the potential petroleum savings would justify the associated sacrifice of auto function and government intervention in the auto market. Behind this issue are major uncertainties, among which the most important is the extent to which nuclear and coal-fired electric power plants will actually be built in Los Angeles. The petroleum savings shown in Table 9.1 assume that regional utilities will construct major new nuclear plants, but as yet the necessary approvals for construction of such plants have not been issued. In fact, there is intense debate over the overall desirability of nuclear power, and its resolution is not yet clear. If nuclear plants are not constructed for Los Angeles, and if electric cars were then recharged from oil-fired power plants, the petroleum savings in Table 9.1 would be reduced by factors of 3 and 4 or more.

Moreover, the significance of any given level of petroleum saving is also uncertain, because it will depend greatly on future US dependence on foreign oil sources. In the baseline projections of this study, independence of foreign sources was projected for the late 1980s, partly due to improved fuel economy of conventional automobiles, partly due to much-increased use of nuclear electric power. To the extent that this independence is thus achieved, additional petroleum savings due to electric car use may not hold the same significance.

Given these uncertainties in both the magnitude and significance of petroleum savings in Table 9.1, the benefits of future electric car use do not now appear to warrant the loss of auto capability and the market intervention problems involved. Accordingly, it seems preferable to accept the free-market level of electric car use for the Los Angeles area until important net benefits can be confidently foreseen for higher levels of use.

Among the individual cases of Table 9.1, those involving lead-acid battery car use seem least desirable. In 1980, impacts are trivial and the costs of attaining them considerable. In 1990, potential energy savings could be significant, but costs would remain high. Use of nickel-zinc battery cars in 1990 would be much preferable: energy savings would be greater, dollar costs no more unfavorable, and auto capability much less impaired due to the much greater daily driving range. Use of the zinc-chlorine and lithium-sulfur battery cars would be better still, largely due to lower anticipated costs. Of these two cars, the zinc-chlorine battery car appears preferable for its lower energy consumption and costs; but these estimates are uncertain, and the lithium-sulfur battery's projected higher energy density offers greater driving range and performance potential.

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Impacts of the use of electric cars in the Los Angeles region in 1980-2000 were projected for four-passenger subcompact elecric cars using lead-acid and advanced batteries, with urban driving ranges of about 55 and 140 miles, respectively. Data from Los Angeles travel surveys shows that such cars could replace 17-74 percent of future Los Angeles autos with little sacrifice of urban driving. Adequate raw materials and night-time recharging power should be available for such use in the Los Angeles Region. Air quality improvements due to the electric cars would be minor because conventional automobile emissions are being drastically reduced. The electric cars would save little energy overall, as compared to conventional subcompacts, but would save a considerable amount of petroleum if they were recharged from the nuclear power plants that are planned. The electric subcompacts would be 20-60% more expensive overall than conventional subcompacts until battery development significantly reduces battery depreciation costs.

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A STUDY OF LOW-POLLUTION POTENTIAL VEHICLES — ELECTRIC

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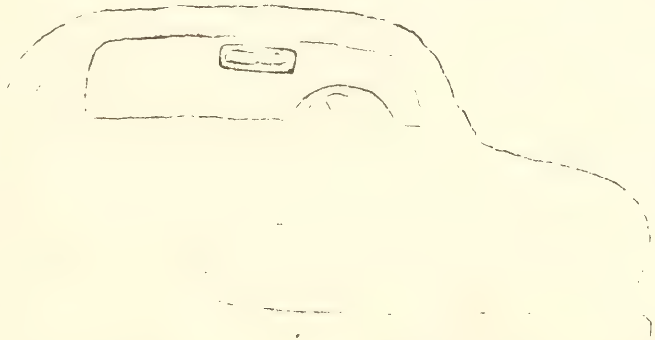

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by

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for

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I. SUMMARY

A. PURPOSE AND SCOPE

This report presents the results of a study conducted by Arthur D. Little, Inc. for the National Center for Air Pollution Control concerning electrically powered vehicles of low pollution potential. A parallel study concerning unconventional thermal, mechanical, and nuclear power sources for vehicles has recently been completed by the Battelle Memorial Institute – Columbus Laboratories.*

The major purpose of the present study is to assess the state of the art in the technologies on which the future development of electric highway vehicles depends. The assessment is made on the basis that there will be no major change in the patterns of urban transportation and focuses upon the technical requirements of the vehicle. As a framework for the study, technical and, to a lesser extent, cost criteria were established for six classes of electric vehicles, most of which correspond closely in performance to existing conventionally powered types. On the basis of these criteria the prospects for vehicle application of various electric motor and control systems and a wide range of electrical power sources including batteries, fuel cells, and engine-generator-battery hybrids are compared. The study identifies the most promising systems for further development and estimates the magnitude of the shortfall in their present characteristics. Recommendations are made for the expansion of future effort in these areas, taking into account the expected contributions from existing programs in the public and private sectors of the economy.

B. FINDINGS

(1) The technical state of the art in motors and controls is generally more advanced than that of power sources in relation to the needs of electric highway vehicles.

(2) Minimum energy and power densities for electrochemical power sources capable of giving acceptable performance in the six classes of vehicles are listed below. The figures are based on reasonable estimates of the weight assignable to the power source and propulsion system and of the weight of suitable electric motors and controls.

	Family Car	Commuter Car	Utility Car	Delivery Van	City Taxi	City Bus
Conventional construction						
Energy density (w-hr/lb)	135	41	26	50	96	81
Power density (w/lb)	94	46	40	55	45	36
Lightweight construction						
Energy density (w-hr/lb)	87	28	18	33	64	55
Power density (w/lb)	60	31	28	36	30	25

---

* Battelle Memorial Institute, "Study of Unconventional Thermal, Mechanical, and Nuclear Low-Pollution-Potential Power Sources for Urban Vehicles," by J. A. Hoess, *et al.*, Summary Report to U.S. Dept. of Health, Education and Welfare, March 15, 1968.

(3) In a hybrid power source the important technical parameter for the battery is the power density, energy density is of only secondary importance. The power densities required for batteries in vehicles of conventional construction having 40% of the peak power supplied by a gas piston engine and 60% by a battery are as follows.

	Family Car	Commuter Car	Utility Car	Delivery Van	City Taxi	City Bus
Power density (w/lb)	92	38	34	43	35	25

For the family car, the power density requirement is virtually equal to that for a purely battery powered vehicle; for the other vehicles the requirement is not much lower.

(4) The technical requirements for the family car power source can be met only by high temperature alkali-metal batteries; these systems, as yet in the early stages of development, are also the most promising for the commuter car, the delivery van, and the city taxi. If lightweight construction is used metal-air batteries are potentially capable of meeting the requirements for all vehicles except the family car. Alkali-metal batteries with organic electrolytes seem likely to have insufficient power density for use in vehicles, and combining them with high-power-density batteries is clearly too costly a solution

(5) Although of limited energy density the lead-acid battery seems likely to be capable of meeting the requirements of the utility car of lightweight construction.

(6) The fuel cell's prospects as an electric vehicle power source seem unfavorable, mainly because of its extra complexity and cost and its lower power density. Its much simpler mode of refueling, however, would be a major advantage.

(7) The most practical present choice of motor for an electrical vehicle is a high-speed dc machine with mechanical commutator, operating at speeds of up to 19,000 rpm for the smaller vehicles, air cooled, and with integral speed reducers. Such motors are already being developed for aerospace and military applications.

Control of high-speed dc motors is best achieved by a chopper circuit containing silicon controlled rectifiers (SCR's). These circuits are at present rather heavy for the amount of power they control. However, they can be developed for operation at high voltage (500 volts in the case of the bus and family car) so as to be relatively lightweight.

(8) Because ac motors can be run at higher maximum speeds, they have a higher output per pound than dc motors and hence permit weight reduction; these will doubtless be adopted when the technologies for inversion and control are further advanced. The development of solid-rotor ac motors instead of the squirrel-cage induction type will lead to greater weight reduction and simplify the problems of inversion and control.

The controller for the ac motor would be a variable-frequency, variable-voltage SCR inverter circuit. Experimental circuits developed to date are, however, extremely heavy and require capacitor banks across the battery when an induction motor is used.

(9) Regenerative braking would reduce the power source requirements somewhat for vehicles that make frequent stops. However, for the majority of vehicles, the amounts of energy recovered do not appear likely to justify the added cost and complexity.

(10) The recharging of electric vehicles is best achieved at slow rates. Rapid recharge would call for large investment in facilities and would introduce a number of severe technical difficulties. Occasional long trips could be accomplished by replacement of batteries at service stations.

(11) The first costs of electric vehicles will inevitably be higher than those of equivalent internal-combustion-powered vehicles. Part of this may be offset by lower maintenance requirements and longer life, but much of the difference would have to be regarded as a social cost for the elimination of air pollution. If an additional $1,000 is acceptable in the retail cost of the family car, the cost target for the battery is in the vicinity of 95 cents per pound. Allowable costs in the commercial vehicles would be somewhat higher. High-temperature alkali metal batteries have some prospects of meeting these cost requirements. Metal-air batteries are likely to be somewhat costlier but might still be acceptable for commercial vehicles.

(12) The duplication in functional capabilities tends to give hybrid vehicles a fundamentally higher cost structure than pure electrics. The higher cost may, however, be acceptable in commercial vehicles, and existing technology would permit low cost lead-acid batteries to meet the power density requirements of a hybrid city bus, making this vehicle an attractive possibility.

(13) Present federal spending on research and development on electrochemical power sources, and exclusive of the major fuel cell hardware programs for space vehicles, is estimated to be in the vicinity of $10 million annually. However, only a small proportion of this is directly relevant to the needs of electric vehicle development for civilian use. Expenditure by private industry on power source development relating to electric vehicles is estimated at $5-7 million annually.

(14) The time scale for the development of electric vehicles will be determined mainly by progress in battery technology and by the magnitude of the effort which sustains it. Assuming that the latter is adequate, high-temperature alkali metal batteries appear likely to require a period of the order of ten years before they can be considered as practical and economic power sources for use in vehicles. Certain metal-air systems, having promise for application in commercial vehicles, might be made available in a somewhat shorter period. At least comparable periods of time would be needed to develop sufficiently low cost manufacturing processes for the motors and controls.

C. RECOMMENDATIONS

(1) The power source requirement for electric vehicles calls for a major and sustained effort in the development of batteries with high energy density and high power density. The requirements for the most significant classes of vehicles can be fully met only by batteries having alkali-metal anodes and molten salt (or possibly ceramic) electrolytes, which necessitate high temperature operation. If such batteries are to be brought to maturity within a ten-year period a coordinated program under federal sponsorship should be set up to do the following:

(a) Explore comprehensively the electrochemistry of the limited number of elements having the reactivity and potential low cost availability to function as anode or cathode materials in high-temperature alkali metal batteries. The physical chemistry of molten salt and ceramic systems appropriate for use as electrolytes should also be investigated.

(b) Examine the materials selection problems associated with such batteries, giving particular regard to choice of current collectors, separators, sealants, and structural materials generally.

(c) Investigate suitable low-cost engineering solutions for the problems of thermal insulation, temperature control, and safety, which are common to all members of this class of batteries.

(d) Develop, in collaboration with industry, the one or two most practical battery systems arising from these research programs.

(2) Support should be given to the further development of rechargeable metal-air batteries. For those of relatively conventional design the principal problems rest with the basic electrochemistry. Other types, which employ engineering solutions to the fundamental electrochemical difficulties, should be supported in the development stage.

(3) The development of high rate lead-acid batteries should be supported in view of their prospects in hybrid-powered commercial vehicles.

(4) The problems of adapting the technologies of high speed air-cooled dc commutator electric motors and of sophisticated dc chopper controllers for low cost mass production should be investigated. Studies should be initiated as to the techniques – such as extensive automation and use of microelectronic modules – by which cost reductions might best be achieved.

(5) Possible techniques for the low cost manufacture of solid-rotor synchronous ac motors and of squirrel-cage ac induction motors with inverters should be investigated. The technology of these machines (known also as brushless dc motors) would also benefit directly from the advances in dc chopper controllers and high-speed dc motors.

(6) Some general encouragement should be given to developing the use of lightweight materials, particularly plastics, reinforced and otherwise, and the lighter metals, for use in present day conventional automobiles. Advances in this area will help to hasten the advent of electrically powered vehicles by lessening the severity of the requirements on the power source. Similar considerations hold for tires designed to minimize rolling resistance.

(7) The potential merit of electric vehicles, relative to other approaches toward alleviation of the air pollution problem, should be periodically re-evaluated in the light of the progress and pattern of development taking place in the various contributing technologies.

II. APPROACH

The pollution of the atmosphere by the exhaust products of the internal combustion engine, particularly in the cities, is a subject of increasingly serious concern. Viewed as a purely technical problem, abatement can be approached in several ways The most straightforward is to modify the engine and exhaust system with devices which will either suppress pollutants or convert them into less noxious products A great deal of effort is presently being expended in this approach, and it may well prove to be the most satisfactory for the immediate future. However, the tendency of an internal combustion engine to pollute increases with its age, and the effectiveness of conversion devices, usually involving catalytic combustion, decreases with time; thus the suppression of pollution may be adequate in a new vehicle but quite unsatisfactory by the time it is two or three years old

Another approach is to replace the internal combustion engine with a type of prime mover that has no significant pollution problem. In principle there are a large number of possibilities, including electric power sources, external combustion systems, inertial energy systems and a variety of exotic energy conversion devices. In practice, however, the practical options are quite limited.

A third approach is to alter the transportation system through major changes in conventional public facilities or through such concepts as the rental of small, self-driven, taxi-like vehicles for journeys within the urban centers.

The subject matter of this study is concerned with the second general approach and specifically with the prospects for self-propelled electric vehicles.

It is necessary to make numerous assumptions as the basis for a study of this type, many of them rather arbitrary, and many of them having a significant bearing on the findings of the study. We are well aware of this and consider our work as a first approximation which may suggest directions for further more refined and specific analysis.

The study is based upon a consideration of the requirements for six types of electric vehicles a family car, a commuter car, a utility car, a delivery van, a city taxi and a city bus. With the exception of the utility car these represent the great majority of vehicles that now provide transportation in the urban environment. The model for the family car is the familiar full-sized, six-passenger automobile, which represents almost 80% of the total vehicle population of this country. The commuter car is modeled on the much smaller, four-seater, European-type compact car, whose population has been steadily increasing in recent years, primarily for commuter travel. The delivery van is somewhat less well defined but can be regarded as a typical panel truck with a carrying capacity of about one ton The city bus is the characteristic full-sized vehicle with a carrying capacity of about 80 passengers including standees The other two vehicles contain an element of invention. The city taxi is outwardly similar to the family car but has been arbitrarily assigned lower performance capabilities in view of its working pattern in the dense traffic of city streets The utility car is a small vehicle intended purely for local trips, such as might be taken by a housewife on shopping errands or possibly for short-range commuting. While each of these vehicles is a candidate for electric propulsion in its own right, it is clear that the greatest interest attaches to the family car in view of its preponderance in the total vehicle population.

The first step in the selection of weight and performance parameters for the various vehicles involved an examination of the published data for virtually all vehicle models manufactured over the last ten years in the United States and Western Europe. From these vehicle specifications, reasonably appropriate values were established for weight and performance in each of the classes The calculation of power requirements necessitated some assumptions about frontal cross-sectional area, degree of streamlining, and tire friction The values chosen for the drag coefficient were liberally low, reflecting the best present aerodynamic design practice, while the estimates for tire friction were conservative, since there is some element of compromise with safety in the design of low-friction-loss tires.

The parameters for acceleration are believed to represent reasonable values for new vehicles. It would not be fair, however, to insist that the electric vehicle should have an acceleration equal to that of a typical new, carefully tuned vehicle with a conventional engine. The performance of an electric vehicle should remain fairly constant with time, while that of most conventional vehicles is at least fractionally lower than when new after three or four years on the road. Accordingly, adverse weighting of the vehicles that formed the basis for the assumed parameters was at least partially offset by considering only vehicles whose power capabilities were on the lower side of normal. Thus, the acceleration for the family car is typical of that for a six-cylinder vehicle, even though more than 80% of the vehicles in this category now have eight-cylinder engines.

Probably of even greater influence on the findings of the study than the assumptions about performance are those about driving cycles and their relationship to vehicle range. The energy consumed by a vehicle per mile of driving is very heavily influenced by the number of stops made, by the rate of acceleration, and by the velocity. The selection of any particular driving pattern thus has a major effect on the range obtainable from a given quantity of stored energy. Fortunately, the arbitrariness of the assumption is partially offset by the fact that vehicles are generally driven at relatively high speed when not in stop-and-go traffic, the energy consumption per mile is therefore very much more constant than it would be if people were in the habit of driving at modest speed on the open road.

The technical requirements for the six classes of vehicles have been established by the following procedure. The maximum power requirements corresponding to the maximum acceleration performance assumed for the vehicles were first calculated, this provided a basis for setting the power rating of each vehicle. The requirements for stored energy were calculated from the energy expenditure for each vehicle when following a standard urban driving cycle. (Since the driving pattern for the city bus involves an unusual number of stops per mile, a separate driving cycle was developed and used for this vehicle.) Assumptions about total range varied with the type of vehicle, in general, the criterion was to take a relatively low value but one that would be justifiable in the application for which the vehicle was intended For example, the family car has a range of 200 miles, the commuter car 100 miles, and the utility car only 50 miles

To bring into focus the technical requirements for electric vehicles, our approach has been to remove conceptually from the conventionally powered vehicles those components (engine, transmission, radiator, muffler, etc) which are inseparably associated with the functioning of the internal combustion engine and to replace them with an electrical power source, motors, and a control system of equal total weight. This procedure considers electric vehicles as modifications and neglects the possibilities of weight optimization which would result from special design. Our basis has been some prior work by Hoffman,* who analyzed the weights of the components of a great many vehicle models and found a recurring pattern in the weight distribution. Among passenger cars whose size and power varied over a wide range, for example, the weight of the replaceable components was never far from 35% of the curb weight of the vehicle. Hoffman also considered the proportion of vehicle weight which could be assigned to the power source and propulsion unit if lightweight materials such as plastic body panels and magnesium frames were used. He concluded that this would raise the allowable proportion to 50%. Our analysis has been conducted on the bases of both conventional and lightweight construction, using proportions close to Hoffman's for the cars and estimated values for the delivery van and city bus.

A major element in our further analysis is the assumption of representative weights for the motors and controls used in these various vehicles so that a total weight could be allocated to the power source. The pattern of the study is thus to relate the prospects for the electric vehicle largely to the requirements of its power source. The justification for this assumption is that the technology in the electrical and electronic areas is relatively further advanced toward the vehicle objective than is that of electrochemical power sources. Projections in these areas can thus be made with relatively greater confidence. The derived results of the above calculations are then expressed as requirements for energy density (watt-hours per pound) and power density (watts per pound) for the power source.

Power source volume is also of some significance, but to a first approximation it would seem secondary to considerations of weight. The great majority of the possible power sources which are candidates for vehicle application have densities which are broadly comparable with each other and with the power systems they would replace Moreover, the electrochemical power sources would seem to have greater flexibility for utilizing internal space within the vehicle.

The question of mechanical-electrical hybrid power sources has also been considered as part of this study, although practical power systems of this type would inevitably produce some degree of air pollution. No attempt has been made to consider the relative merits of various hybrid approaches on the basis of their relative contribution to air pollution; they have been regarded solely as alternative electrical power sources. The approach was to assign the available power source weight to the engine-generator-battery combination and from the estimated weights for the first two components determine the power densities required from the battery.

Much of this report is concerned with a review of the present and projected state of the art in the technologies of electric motors and control systems and electrochemical power sources. Using the technical requirements of the electric vehicles as a yardstick for assessment of present achievement and future progress, we have developed some conclusions and recommendations concerning the preferred direction for further effort

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* G. A. Hoffman, *Transportation Research*, Vol. 1, No. 3, 1967.

The question of costs is of comparable importance but is even more difficult to bring into focus, since it frequently relates to manufacturing processes which in many cases are barely in the conceptual stage Such conclusions about costs as can be drawn are, however, integrated into our assessment of the needs for further research and development programs.

The conclusions to be drawn from our study, while cautiously optimistic for the prospects of electric vehicles, are not to be interpreted as indicating the likelihood of their imminent appearance. A vast amount of further technical effort is called for if the large-scale use of electric vehicles is to become a reality, even twenty years from now Nevertheless it seems that it can be done, and the effort should be made if the social cost of air pollution is sufficiently great and other approaches to the problem are less attractive. Such decisions, however, are in the political realm, this report is to be considered primarily as a contribution to the technical evaluation of the problem.

III. CRITERIA FOR ELECTRIC VEHICLES

A. DEVELOPMENT OF VEHICLE SPECIFICATIONS

In this section technical criteria are established for the six classes of electrical vehicles. As a basis for this, the electric vehicles have been considered as comparable alternatives to existing vehicles powered by internal combustion engines. Though new requirements for vehicles do appear from time to time, one year's car generally behaves very much like another's, and motorists have become accustomed to certain kinds of response from the vehicles they drive. This is not to say that all of today's vehicles show identical performance but, rather, that there are minimum standards of acceleration and comfort to which any new vehicle must conform if it is to achieve commercial success. Furthermore, any vehicle which cannot perform like most of those with which it mingles presents a serious hazard on crowded roads.

In addition to performance, the vehicle controls must be similar in "feel" to those of conventional vehicles. This, however, is largely a matter of proper design of the electrical controls and does not necessarily involve weight and power consumption.

The choice of vehicles and of vehicle parameters for this study (Table 1) were made after discussions with representatives of the National Center for Air Pollution Control and Battelle Memorial Institute Most of these vehicles represent types of conventional motor vehicles now used in and around our cities. For completeness, we have included in the study a "utility" vehicle, whose performance is not comparable with that of today's highway vehicles but which may find acceptance in specialized uses and locations. Its specifications correspond closely to those of many of the electric vehicles developed in the United Kingdom.

The reported performances of a number of selected types of internal combustion powered vehicles in each of the six classes were examined and norms were established for their maximum acceleration, these figures are tabulated on lines 1 and 2. Using the actual acceleration curves as a guide we then drew standardized acceleration curves and normalized them to the acceleration specifications. These curves, shown in Figure 1, were used as the basis for all further calculations of maximum power and energy requirements.

The maximum performance of a vehicle can be concisely stated as the relationship between velocity and time while it is driven from rest at full power. It is not necessary to consider grade climbing separately, because at any given speed there is a simple relationship between maximum level-road acceleration and grade climbing ability

The weights assigned to the vehicles listed in Table 1 were based on data for current vehicles of similar capacity and performance The weights assignable to propulsion, energy storage, controls, etc in line 7a were obtained by use of the general procedure of Hoffman[*] i.e., by totaling the weights for all those components of the conventionally powered

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[*] *op cit.*

ELECTRIC VEHICLE SPECIFICATIONS

Assumptions		Family Car	Commuter Car	Utility Car	Delivery Van	City Taxi	City Bus
1 Acceleration to	(mph)	60	60	30	40	40	30
2. in	(sec)	15	30	10	20	15	15
3. Range	(mi)	200	100	50	60	150	120
4. Seats or payload	(lb)	6	4	2	2,500	6	10,000
5. Loaded weight*	(lb)	4,000	2,500	1,700	7,000	4,000	30,000
6. Curb weight	(lb)	3,500	2,100	1,400	4,500	3,500	20,000
7. Weight assignable to propulsion, energy storage, controls	(lb)						
a. conventional construction		1,250	750	500	1,400	1,250	5,000
b. lightweight construction		1,750	1,050	700	2,000	1,750	7,000
8. Frontal area	(ft^2)	25	18	18	42	25	80
9. Drag coefficient		0.35	0.25	0.25	0.85	0.35	0.85
10. Elec. transmission efficiency	(%)	82	77	72	79	76	85
Derived Parameters							
11. Max. power delivered by motors	(kw)	70	22	12	49	36	135
	(hp)	94	30	16	66	48	180
12. Max. output of power source	(kw)	85	29	17	62	47	159
13. Max. velocity	(mph)	100	80	65	56	77	55
14. Delivered energy	(kwh)	100	20	8	45	75	300
15. Stored energy	(kwh)	122	26	11	57	99	353
16. Weight of motors, transmission, and controls	(lb)	348	118	82	259	210	615
17. Weight assignable to power source	(lb)						
a. conventional construction		902	632	418	1,141	1,040	4,385
b. lightweight construction		1,402	932	618	1,741	1,540	6,385
Power Source Requirements							
18. With conventional construction							
energy density	(w-hr/lb)	135	41	26	50	96	81
power density	(w/lb)	94	46	40	55	45	36
19. With lightweight construction							
energy density	(w-hr/lb)	87	28	18	33	64	55
power density	(w/lb)	60	31	28	36	30	25

*The loaded weights given for the cars and taxi are not the maximum which they are capable of carrying but rather reflect typical usage.

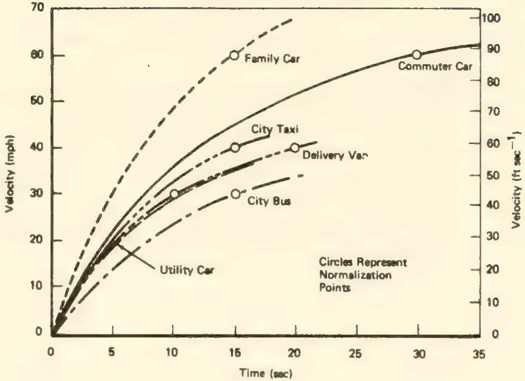

FIGURE 1 STANDARDIZED ACCELERATION CURVES

vehicles which would not be required in the same form in an electric vehicle The assignable weight for vehicles with conventional construction is shown on line 7a and for lightweight construction on line 7b.

The values chosen for the range of the electric vehicle, line 3, are on the low side of average for internal combustion powered vehicles in the case of the family car, city taxi and city bus. For the commuter car, utility car, and delivery van, we chose values which might represent reasonable daily ranges for vehicles which are not likely to be used continuously for long periods.

B. POWER AND ENERGY CALCULATIONS

Two sets of calculations are needed to define the power and energy requirements of a vehicle. First, we must know the maximum power and the velocity at which this maximum occurs Second, we must calculate the total energy consumed when the vehicle operated under various driving conditions

1. Power Requirements

The power expended by the vehicle can be represented by the following expression

instantaneous power = velocity [mass x acceleration
+ aerodynamic drag + rolling resistance]

The maximum power requirement is determined by expressing all the quantities on the right hand side in terms of velocity as a variable The expression is then differentiated and the resulting function put equal to zero

a. Acceleration

The first step was to express the maximum linear acceleration in terms of velocity This was done by synthesizing simple analytical expressions which fitted the graphical data reasonably well within the normalization limits of the performance curves These expressions,* which are shown graphically in Figure 2, are as follows

Family Car $a = 20 \quad 0.500v + 5.3 \times 10^{-3}v^2 \quad 2.2 \times 10^{-5}v^3 \quad 8(1 + 10^{-3}v^3)^{-1}$

Commuter Car $a = 7.0 - 0.028v - 1.3 \times 10^{-3}v^2 + 0.9 \times 10^{-5}v^3$

Utility Car and Delivery Van $a = 6.6 - 0.046v - 1.3 \times 10^{-3}v^2 + 0.7 \times 10^{-5}v^3$

City Taxi: $a = 5.2 - 0.006v - 5.3 \times 10^{-3}v^2 + 7.0 \times 10^{-5}v^3$

City Bus: $a = 9.0 - 0.053v \cdot 3.0 \times 10^{-3}v^2 + 3.0 \times 10^{-5}v^3$

From these expressions, the power expended on linear acceleration during periods of maximum acceleration can be expressed as a function of v, namely

$$\frac{Mav}{g}$$

If the power required for rotational acceleration is assumed to be 10% of that for linear, the total power used for acceleration is

$$\frac{1.1\ Mav}{g}$$

b. Aerodynamic Drag

Estimates given in the literature for power consumption caused by aerodynamic drag vary considerably. For example, using a 2000-lb vehicle traveling at 60 mph, Hoffman* finds 9.7 hp and the Morse panel** finds 17 hp Basically, the reason for these discrepancies is varying judgments as to the practicability of employing good aerodynamic body styling. We take an optimistic view and believe that the arguments of Tenniswood et al † are sound. These authors reason that the incentive to reduce air resistance in gasoline-propelled vehicles is comparatively weak, because no initial cost saving is achieved, in electric vehicles, however, particularly those designed for high speed, it can affect first cost by reducing the battery capacity required for a given range. We believe that, compared with the problems of developing satisfactory power sources, improving the aerodynamic characteristics of vehicle bodies would be relatively easy. We have therefore employed optimistic values for the drag coefficients, C_D, in the following expression

$$\text{Drag force} = 1.19 \times 10^{-3}\ C_D A v^2 \ \text{pounds}$$

The values assumed for frontal area, A (Table 1, line 8) reflect a moderate degree of streamlining.

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* The symbols and units used in the analytical expressions are as follows

a	acceleration (ft sec^{-2})	W	weight of vehicle [illegible]
A	frontal area (ft^2)	s	distance travelled (ft)
C_D	drag coefficient (dimensionless)	t	time (sec)
g	gravitational constant (32.2 ft sec^{-2})	v	velocity (ft sec^{-2})

*op cit.

**The *Automobile and Air Pollution A Program for Progress*, Report of the Panel on Electrically Powered Vehicles (R.S. Morse, Chairman), U.S. Dept. of Commerce, October 1967.

†D.M. Tenniswood and H.A. Graetzel, Ford Motor Co. (SAE paper no. 670177), 1967.

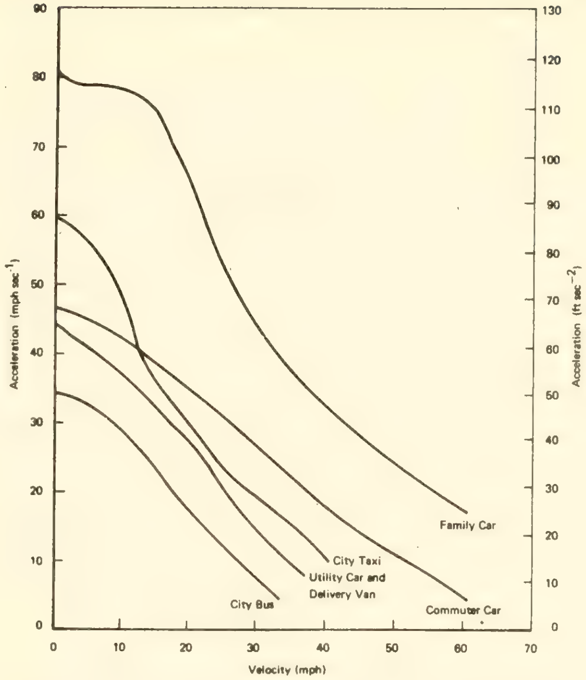

FIGURE 2 ACCELERATION VERSUS VELOCITY FOR SELECTED VEHICLES

c. Rolling Resistance

When a vehicle moves at uniform velocity over a smooth road, that portion of resistance which is not due to aerodynamic drag results principally from the work done in distorting the tires, together with a small addition from wheel bearing and gearbox friction. Some authorities, such as the **Morse** panel, treat rolling resistance as a constant force dependent upon tire characteristics and vehicle weight, but this does not agree with the data presented by Tenniswood et al., Hoffman, and Stiehler et al.* Combining the available data, we have derived an empirical equation relating rolling resistance to vehicle weight and speed. If the latest developments in low-loss tires are employed, the resistance would be less than the values calculated from the equation, but we have taken a cautious approach for the following reasons: 1) much of the reduction in rolling resistance of improved tires is lost if correct inflation pressures are not maintained; 2) a soft ride may be demanded by buyers of electric automobiles, and on rough roads this would require that energy be absorbed either in the tires or by the suspension system; 3) federal safety requirements for tires cannot at present be met by tires with very low rolling resistance.

Our empirical expression for the rolling resistance, which also includes the losses in the gearbox and bearings, is:

$$\text{Rolling resistance} = \frac{M}{50}\,(1 + 1.4 \times 10^{-3}v + 1.2 \times 10^{-5}v^2)\ \text{pounds.}$$

d. Calculations of Maximum Power

The final expression for instantaneous power under conditions of maximum acceleration is thus:

$$\frac{v}{550}\left[\frac{1.1\,Ma}{g} + 1.19 \times 10^{-3}\,C_D A v^2 + \frac{M}{50}\,(1 + 1.4 \times 10^{-3}v + 1.2 \times 10^{-5}v^2)\right]\text{horsepower}$$

where a is related to v by the expressions given above in subsection a and the factor 550 converts ft lb sec^{-1} to horsepower. This expression is plotted in Figure 3 for the family car. In this case the total power requirement does not pass through a maximum value in the velocity range of 0-60 mph, and the conditions for maximum power are those for maximum acceleration at 60 mph. A number of the other vehicles show maxima at velocities in the 20-40 mph range. Values for the maximum power, which is that delivered at the output of the gearbox, are shown in line 11 of Table 1.

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* R. D. Stiehler, M. N. Steel, G. G. Richey, J. Mandel, and R. H. Hobbs. *J. Res. Nat. Bur. Std.*, Vol 64 C, 1960.

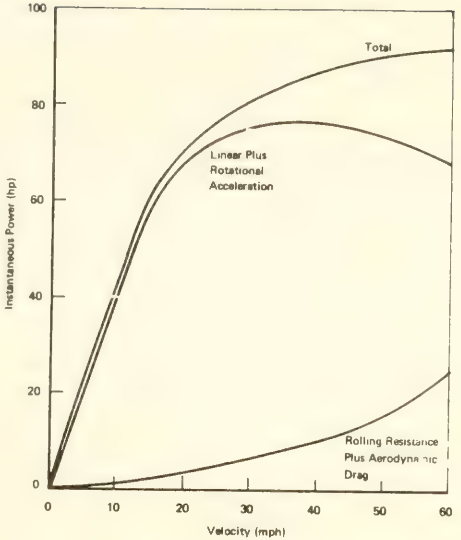

FIGURE 3 POWER REQUIREMENTS FOR THE FAMILY CAR AT MAXIMUM ACCELERATION

2 Energy Requirements

The energy requirements for each vehicle, corresponding to the values for the range, listed on line 3, are heavily dependent upon the driving cycle or pattern of use involved Thus, for a given quantity of energy stored, the range of an electric vehicle operating nonstop at constant velocity might be several times that when operating in city traffic with frequent stops.

The selection of an appropriate driving cycle is somewhat arbitrary After consultation with representatives of the National Center for Air Pollution Control, we have adopted for all vehicles except the city bus, the "Public Health Service Cycle" derived from a driving cycle (LA4) based on studies in the city of Los Angeles This cycle is set out in Table 2 For the city bus, another cycle was devised which reproduces the statistical observation that its average velocity is 12 mph and that it makes ten stops per mile, this cycle is shown in Table 3

On the basis of these driving cycles and the assumed parameters for the vehicles, we calculated the delivered energy requirements for the various ranges. These are shown on line 14 of Table 3 The requirements for stored energy, line 15, were derived by dividing the delivered requirement by the electric transmission efficiency

C ELECTRIC TRANSMISSION PARAMETERS

The weights allotted to the motors, control systems, cabling, etc for the six classes of electric vehicles have been estimated on the basis that high-speed dc motors with silicon controlled rectifier chopper control circuits would be the most appropriate system The factors affecting this choice are considered later, in Section IV This subsection contains details of the specifications for the various components of the electrical transmission for each class of vehicle

One of the fundamental characteristics of electric motors and electromagnetic machines in general is their ability to deliver a constant torque over their entire speed range By proper control, a motor can be made to deliver its rated torque or fraction thereof at any speed from zero up to the physical limit of its rotating member By overloading the motor, one can produce 150% to 200% torque for short periods of time, the amount of overload torque obtainable and the length of time the motor can deliver it without damage depend on the details of the design of its motor particularly as it affects thermal capacity Since horsepower is the product of torque and speed the maximum horsepower from a given size motor is obtained by operating it at its highest speed The rated maximum speed is dictated by the [illegible] stress limit of the rotor These fundamental motor relationships are summarized in Figure 4

TABLE 2

PUBLIC HEALTH SERVICE CYCLE

Velocity Mode (mph)	Mode Time (sec)	Cumulative Time (sec)	Acceleration Rate (mph/sec)
0	30	30	–
0-19	8	38	+ 2 38
19	15	53	.
19-44	12	65	+ 2.08
44-52	7	72	+ 1.14
52	9	81	–
52-37	12	93	– 1.25
37	16	109	–
37-31	5	114	– 1.20
31-0	13	127	– 2.38

TABLE 3

CITY BUS CYCLE

Velocity Mode (mph)	Time (sec)	Distance (ft)	Acceleration Rate (mph/sec)
0-15 7	6.60	76	+ 2 4
15.7	13.30	306	–
15.7-19.0	1.35	35	+ 2 4
19 0-0	7.95	111	– 2 4
	29.2	528	

Average speed = 12 2 mph

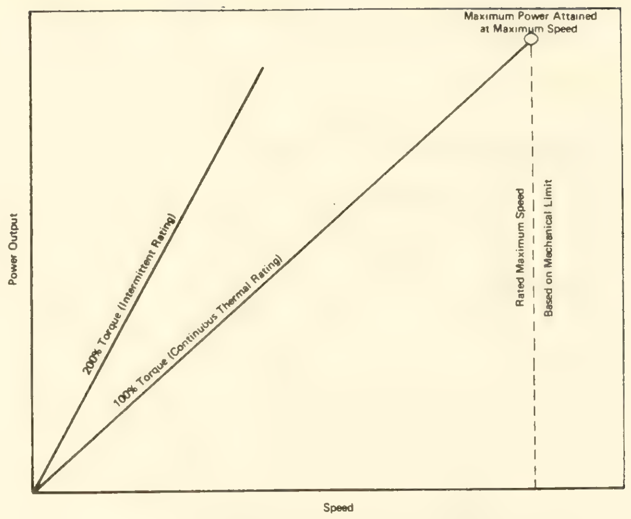

FIGURE 4 POWER-SPEED CHARACTERISTIC CURVES FOR ELECTRIC MOTOR

The selection of one or more motors for a given vehicle application involves matching motor characteristic curves of the type shown in Figure 4 to the power demand profile for the vehicle, such as that for the family car in Figure 3. This matching is shown in Figure 5 where the dashed line represents the characteristics of the smallest dc motor which could meet the power requirements entirely within its rated power capabilities. Since maximum power demand will in practice be relatively infrequent and of short duration, one could safely select a motor which would have these capabilities on 100% overload. The power-speed relationship for the chosen motor is shown by the solid sloping line. It can be seen that the maximum power output of which this motor is capable and which is attained at its maximum motor speed will be significantly greater than the maximum power demand of the vehicle. The vehicle cannot, however, use a smaller motor because of its need for substantial power at lower speeds and cannot utilize the full capability of a larger motor because of the limited output of the power source. A smaller motor could be used if a gear changing mechanism or torque converter were inserted into the power train, but such devices are undesirable because they introduce extra weight, cost, and power inefficiency.

The selection of motors is also influenced by certain general engineering considerations. For example, we have chosen to use a motor for each wheel in the family car, delivery van, city taxi, and city bus (the latter being a six-wheel vehicle); this has been done to obtain certain benefits resulting from separate control of the power applied to the individual wheels.* Normally, the use of several small motors rather than one large motor would incur a weight penalty: for motors of a given speed, the power output per unit weight increases with increasing size, since magnetic and thermal designs become more efficient. This characteristic can be offset, however, by designing the smaller motors to operate at higher maximum speeds.

Estimates of the weights of these high-speed dc motors have been based on dc machines now used in aerospace and torpedo propulsion applications. It is assumed that these motors would be cooled by forced air from a separate blower system. The weights of the controllers have also been estimated from existing devices, some of which are being used in lift trucks and other electric motor control applications.

To size the controllers and vehicle cabling, we have had to make assumptions about the maximum voltage for the electrical system in each of the vehicles. The values selected were 500 volts for the family car and city bus, 250 volts for the commuter car, delivery van, and city taxi, and 125 volts for the utility car. Allowance has also been made for the weight associated with the electric cabling, component mounting, cooling system, and a speed reducer for each motor-wheel system.

Estimates based on the present state of the art have also been made for the efficiency of the individual motors and controllers. Speed-reducer efficiencies were already considered in the calculation of energy requirements.

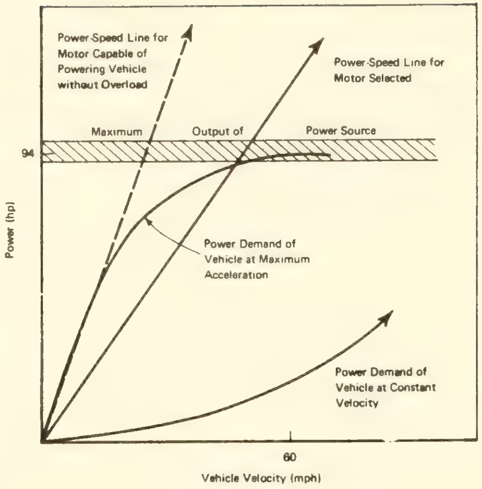

FIGURE 5 MOTOR SELECTION FOR FAMILY CAR

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* A compromise of two wheels per motor was made for the commuter car and the utility car.

The results of these analyses are presented in Table 4 and the total weight of the electric transmission system is entered in line 16 of Table 1. It can be seen that this weight amounts to some 5-6% of the curb weight of all vehicles except the family car (for which it is about 10%) and the city bus (about 3%). The effects of matching the motor to the profile of vehicle power demand can be seen by comparing the estimates for the maximum possible output of the motors in the family car (56 hp) with the maximum actually used (23.5 hp). Each motor thus has a potential output of 1.0 hp per lb but a useful output of only 0.41 hp per lb.

From the values for electric transmission weight presented in Table 4 and included in Table 1, line 16, it is possible to estimate allowable weights for the power source by subtraction from the weights given on lines 7a and 7b of Table 1. The results are shown on line 17. Combining these with the calculated power and energy demand of the vehicle enables us to calculate the required energy densities and power densities for power sources capable of meeting the vehicle specifications. These values are entered on lines 18 and 19 of Table 1 and form the background to the review of the state of the art in electrochemical power sources in Section V.

The approach taken in this study focuses attention on the energy and power capabilities of the power source per unit weight rather than per unit volume. The justification for this is that the average densities of electric motors, controllers, and electrochemical power sources are, with the possible exception of ambient-temperature fuel cells, fairly similar to those of the components they would replace in an internal-combustion-powered vehicle. Moreover, since the electrical system is interconnected by cabling rather than mechanical links, it has greater flexibility for location within the vehicle. Thus it seems reasonable for a first consideration to assume that w-hr/lb and w/lb can be used as yardsticks of the technical merit of a power source for vehicle applications.

The analysis of power and energy requirements carried out here has been concerned only with the demands of the vehicle for mechanical energy. Present-day automobiles use significant amounts of energy for a variety of other purposes. Most prominent are the demands for heating and air conditioning, the former amounting to a maximum of perhaps five thermal kilowatts and the latter to two electrical kilowatts in the average family car. The additional demand for lights and various ancillary power equipment can amount to a sizable fraction of a kilowatt. In our analysis we have neglected these demands, since an auxiliary gasoline-fed burner is probably the most appropriate type of heating device, and air conditioning is not yet regarded in most of the United States as a necessity.

TABLE 4

ELECTRIC TRANSMISSION PARAMETERS

		Family Car	Commuter Car	Utility Car	Delivery Van	City Taxi	City Bus
Maximum power delivered to wheel speed reducers	(hp)	94	30	16	66	48	180
	(kw)	70	22	12	49	36	135
Number of motors		4	2	2	4	4	[illegible]
Maximum power delivered to wheel speed reducers by each motor	(hp)	23.5	15	8	16 5	12	30
Maximum motor speed	(rpm)	13,000	16,000	19,000	16,000	16,000	12,000
Fraction of maximum motor speed at which motor delivers its maximum power* to the wheel speed reducers		0 42	0 48	0.56	0 48	0 42	0.42
Maximum power output of which each motor is capable at its maximum speed	(hp)	56	31	14 5	34.5	28.5	71.5
Weight of motors	(lb)	4 x 57 = 228	2 x 33 - 66	2 x 18 = 36	4 x 36 = 144	4 x 32 = 128	6 x 70 = 420
Motor efficiency	(%)	88	85	80	85	83	90
System voltage		500	250	125	250	250	500
Weight of controller	(lb)	50	30	28	66	48	90
Controller efficiency	(%)	93	91	90	93	92	95
Weight of speed reducers	(lb)	15	6	3	12	8	30
Weight of cables, mounting, etc	(lb)	45	12	12	30	20	60
Weight of cooling system	(lb)	10	4	3	7	6	15
Overall efficiency (excluding speed reducers)	(%)	82	77	72	79	76	85
Overall weight of electrical system (including speed reducers)	(lb)	348	118	82	259	210	615

*Assuming 100% overload capability

IV. ELECTRIC TRANSMISSION SYSTEM

This section discusses the state of the art of electric transmission systems as it applies to the criteria for the vehicle classes arrived at in Section III.

The function of the electric transmission system is to drive and control the speed of the wheels of the vehicle, using the power of the battery, fuel cell, or hybrid power source. The system consists of one or more motors geared through speed reducers to the wheels of the vehicle, a control unit for each motor, and electric cables that join the control units to the power source. Since the control units, motors, and speed reducers have certain unavoidable losses, the resulting heat must be dissipated by a cooling system, the weight of which must be assigned to the electric transmission system.

In a battery-powered vehicle, it is extremely important to have high efficiency throughout the electric transmission system, since battery power is limited. Replacement of the automatic transmission with a fixed-ratio speed reducer increases the overall efficiency, however, some weight penalty is imposed upon the motors, since they are called upon to deliver high torques at extremely low speeds. This weight penalty is not too severe if high-speed motors and large speed reduction ratios are used, as discussed in subsequent sections.

A. MOTORS

The maximum rated speed of a motor depends upon the rotor construction, which varies with the type of motor. The most important limitation is the rotor peripheral velocity, this is determined by the speed and the rotor diameter, as shown in Figure 6 for four types of rotor construction. Obviously, the smaller the diameter, the higher the allowable rotor speed.

For the low-horsepower requirements of small vehicles, motors of relatively small diameter can be used, and thus very high rotor speeds are possible. This helps to counteract the intrinsically greater efficiency of large motors by operating the low-horsepower motors at higher speeds than the high-horsepower motors, one can largely avoid the penalty in pounds per horsepower imposed upon smaller machines. Further significance of the information contained in Figure 6 will be discussed when the relative advantages of ac and dc motors are discussed later in this section.

Since high speed is a requirement for obtaining a high horsepower per pound, it is desirable to have a small diameter and hence a long rotor. At the present state of the art, therefore, only conventionally shaped, cylindrical-rotor dc and ac motors capable of high-speed operation can be considered for vehicle propulsion.

The two unconventional dc motors described below are discussed for the sake of completeness but must be excluded from vehicle use consideration at this time.

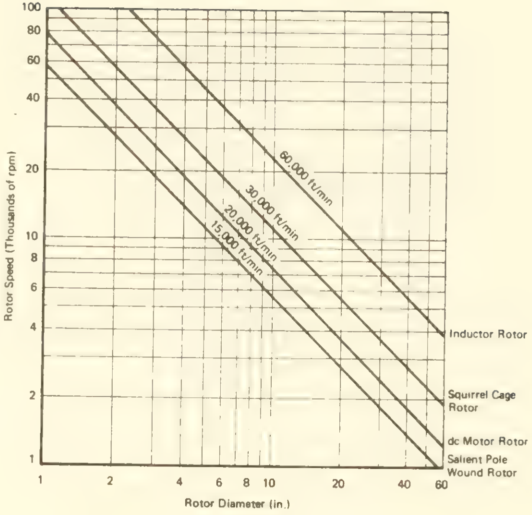

FIGURE 6 ALLOWABLE ROTOR SPEEDS

Pancake-shaped motors, of which the most common is the printed-circuit dc motor, are large in diameter and short in length, consequently they have high rotor stresses at high speeds and are not acceptable for electric vehicles. Widely used in low-inertia, fast-response drives, such motors have axial working air gaps instead of the annular gaps of conventional motors. This produces a different physical configuration, but the torque per ampere is about the same.

So-called homopolar dc motors are unacceptable because, as explained later, the characteristics of control systems do not permit use of any motor which requires extremely high currents and correspondingly low voltages This is unfortunate, since their voltage requirement nicely matches the low voltage available from batteries. Homopolar motors also employ liquid metal brushes, which do not permit the maximum speed that is theoretically possible for the type of rotor construction used The only appreciable application of these machines has been in homopolar generators, these supply extremely heavy currents at a few tens of volts and are desirable because of the smooth dc power they generate.

1. Direct-Current Traction Motors

Direct-current motors have been used for a number of years in electric locomotives and have established a good performance record. These motors have carbon brushes and copper bar commutators and are of series field construction. In this form of construction the armature current establishes the field flux, proper control of the armature voltage provides high torque at low speed and decreasing torque at higher speeds Thus, an approximately constant horsepower characteristic can be achieved over most of the speed range

Since dc traction motors are built in relatively large sizes with high horsepower ratings, they are not usable in their present form for electric vehicle propulsion. However, the general design technology of traction motors for electric locomotives is adaptable to the production of reliable dc motors for electric vehicles. Present traction motors have relatively large rotors and do not operate at the high speeds required for electric vehicles, but the peripheral velocities of the rotor and commutator establish design guidelines for scaling It is customary to have a maximum rated speed which corresponds to commutator peripheral velocities of 12,000 ft/min, with overspeed during wheel slippage of 20,000 ft/min This corresponds to rotor peripheral velocities of approximately 15,000 ft/min and 25,000 ft/min, respectively.

Direct-current traction motors have also been applied to fork lift trucks, delivery vans, and golf carts. In these applications cost did not justify developing the lightest and highest speed motor. Instead, the selection was based on available electric equipment Therefore, these applications do not represent attempts to extend the state of the art.

The applications where effort has been made to obtain the maximum horsepower per pound are in electric torpedo propulsion and aircraft dc generators and motors, even these do not represent the ultimate, however, because their speed is restricted by the nature of the systems in which they are used. If motors for vehicles were designed like these special motors and run at speeds approaching their maximum rated values, they could deliver about one horsepower per pound, at least in the larger sizes.

The effect of speed is illustrated in Figure 7. For a given increase in horsepower per pound, it can be seen that the speed of a small motor must be increased more than that of a large motor. Fortunately, for the range of vehicle horsepower considered in this study, the necessary speeds (12-19,000 rpm, see Table 4) are within the capabilities of today's bearings. The accompanying stresses are within the rated design values, and reasonable brush wear is maintained.

It must be emphasized that the values plotted in Figure 7 are based on the motors' maximum horsepower rating – i.e., the horsepower they can deliver at their maximum rated speed and torque. Normally, aircraft dc generators are not rated in this manner, so published specifications must be carefully interpreted.

Because of the high performance which can be obtained from dc motors and the ease with which they can be controlled, they are currently being used in small electric vehicles and in larger experimental vehicles. In general, they provide a very acceptable interim solution to the electric transmission system. To obtain higher horsepower per pound and eliminate the brush wear problem of the dc commutator motor, however, an ac motor must be used.

2. Alternating-Current Induction Motors

In an induction motor, the rotor is a squirrel-cage arrangement of conductors imbedded in steel. This robust construction permits a high rotor speed (see Figure 6) In addition, the active length of the rotor can be longer than that normally used for a dc commutator motor. These features enable an ac induction motor to have a higher horsepower per pound.

Since the induction motor requires alternating current and the battery provides direct current, one of the functions of the control unit is to act as an inverter, controlling the speed of the motor by varying the frequency of the ac power. The control unit must also provide the proper voltage-to-frequency ratio to enable the motor to deliver its rated torque over the entire speed range. The resulting torque vs speed curve differs greatly from that normally associated with an induction motor, however, it is completely consistent with the principle that any electromagnetic machine is capable of constant torque over its entire speed range.

Induction motors for vehicle propulsion are similar in construction to high-performance aircraft motors of the low-slip variety. Such motors have low-resistance rotors that minimize losses. Normally, low-slip designs would be unsuitable because of their high starting currents, with a current-limiting control, however, starting current is not a problem, and the motor design can be optimized for maximum efficiency.

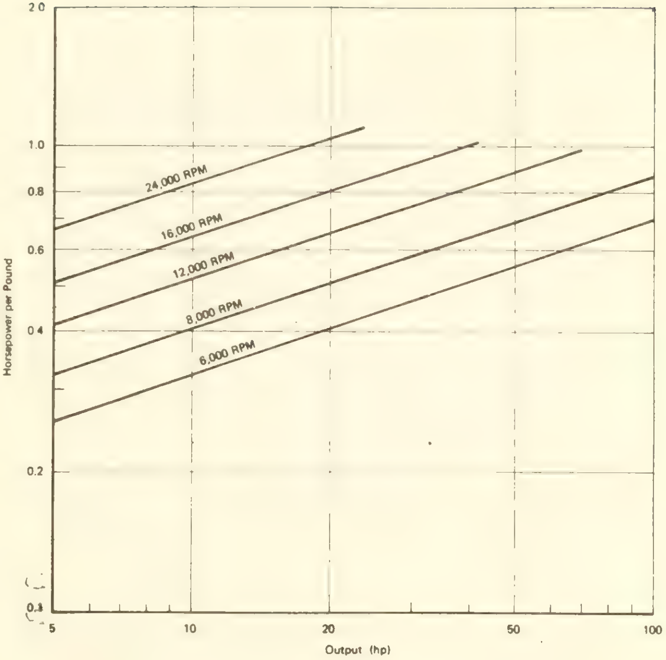

FIGURE 7 WEIGHTS OF DC MOTORS

Recent experimental electric vehicles and rapid transit systems have used induction motors. By taking maximum advantage of their desirable characteristics, manufacturers have been able to build induction motors that provide approximately two horsepower per pound. (This is based on the horsepower at maximum rated speed. induction motors generally lack the overload capability of dc motors, so the figure is an estimate based on 200% overload capability for five minutes.) Figure 8 includes data on two recently publicized induction motors.

Since the above applications have used induction motors of high horsepower, speeds exceeding the 13-19,000 rpm range have not been necessary. It is doubtful that a high horsepower-to-weight ratio could be maintained for lower-rated motors by increasing their speed, because bearing problems would be encountered. However, the use of induction motors eliminates brush wear at the expense of some increase in control unit weight and cost. this advantage will be further discussed later.

3. Synchronous Motors

The synchronous motor is another possible contender for powering future electric vehicles. In this type of motor, ac power is supplied to the stator to produce a rotating magnetic field and the rotor revolves synchronously with the field. The most common design has a "wound field" - i.e., excitation current is supplied to the rotor through slip rings and creates strong north and south poles in passing through the rotor windings. While such a motor must have brushes to make connection with the slip rings, the brush wear is far less than with the commutator of a dc motor.

Nevertheless, a truly brushless motor is desirable because brushes are a possible source of trouble. The simplest form of brushless synchronous motor uses permanent magnets in the rotor and, therefore, needs no brushes, but its power output is too low for vehicular applications. A promising recent development is the solid-rotor brushless machine much work has been done on this design for aerospace generators, and various experimental units have been built. These have characteristically been heavier than comparable motors of wound-field construction, but they have the offsetting ability to be run at higher speeds. Thus advantage cannot be fully utilized in small motors for the lighter vehicles, because their bearings cannot withstand the speeds permitted by the rotor. (Sophisticated, high-performance bearings are too expensive for the uses considered here.) The speed capability of the solid rotor might, however, prove advantageous for applications in vehicles such as buses that require larger, more powerful motors.

The principal advantage of synchronous motors over induction motors is that the former require a lighter, less complex control unit. Synchronous motors receive rotor excitation power directly from the battery, their control units supply power to the stator only. Induction motors, on the other hand, obtain excitation power from the control unit via the stator circuit. As a result, their control units must be more powerful and thus heavier. Furthermore, to prevent excessive heating of the battery, they must provide storage for the excitation power that cycles back and forth from the motor. This storage usually takes the form of a capacitor bank across the battery terminals, which involves a further weight increase.

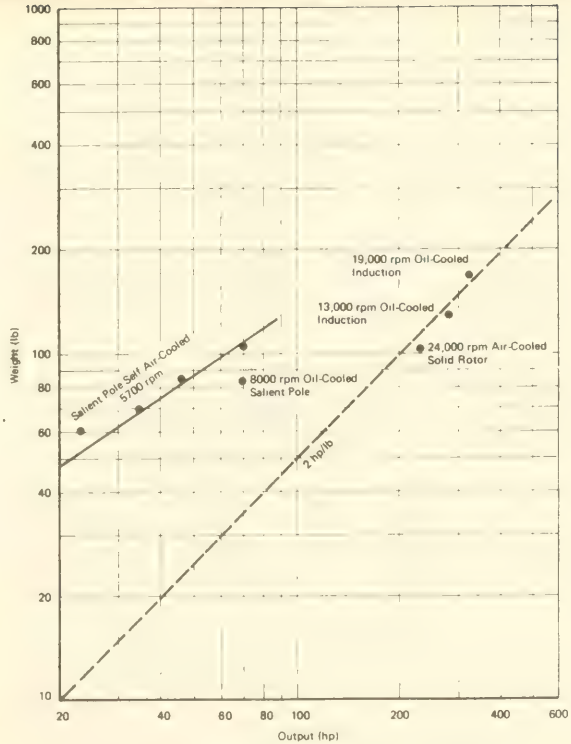

FIGURE 8 WEIGHT VERSUS POWER OF AC MOTORS

Because of this advantage of the synchronous motor over the induction motor, it would be desirable to use synchronous motors. Until the brushless variety is fully developed, the slip-ring, wound-field synchronous motor is perhaps the most desirable solution for powering an electric vehicle, if the higher control cost of the ac motor approach can be justified.

The synchronous motors which might be used could be patterned after aircraft generators. As with aircraft dc generators, the technology is highly developed and is directly applicable to air-cooled and special oil-cooled machinery The weights of a few standard aircraft generators with slip-ring-fed rotors are shown in Figure 8 when rated as motors Also shown is the weight of a solid-rotor machine developed for a high-speed application.

The cost of high-speed air-cooled or oil-cooled motors with integral gear reducers cannot be closely estimated from available data, the requirements for aerospace applications differ greatly from those for mass-produced electric vehicle drive motors, even though speeds, ratings, and technologies are similar As a rough estimate, the manufacturing cost in large quantities of motor and gear reducer might ultimately be about $4 per vehicle horsepower for a dc commutator motor. For an ac induction motor, it might be as low as $2 per vehicle horsepower. The cost of solid-rotor synchronous motors would range between these limits, approaching the upper figure for those of higher speed.

B. CONTROLS

Historically the speed of dc traction motors has been controlled by inserting a resistance in series with the motor so as to regulate the current from the dc power source In addition to switching resistance into and out of the circuit, switching of the field circuit between series and parallel connection is also customary This manner of speed control causes jerky performance and is inefficient from the standpoint of conserving battery power.

Because a battery supplies an essentially fixed dc voltage, and because the speed of a dc machine varies with the input voltage, a control must be used that will effectively vary the voltage with negligible losses. The advent of solid-state devices has made such control possible Instead of reducing voltage by inserting resistance into the circuit, these devices achieve the same effect by rapidly interrupting the current. The longer the interval of disconnection, the lower the average voltage that the motor receives. The motor current is not interrupted during the time that the battery is disconnected, rather, the motor circuit is closed on itself.

The switching elements which are used to disconnect the motor winding from the power source are silicon power transistors or silicon controlled rectifiers (SCR's) The difference between them is that SCR's can be turned off only by reversing their anode-to-cathode voltage for a short time, silicon power transistors can be shut off simply by interrupting their control current Both devices are turned on by applying a low-power pulse to their control terminals In the case of the power transistor, the low-power pulse must persist for the duration of power conduction. Power transistors were initially used, but SCR's are now preferred because of their higher power handling capability, even though they require special turnoff circuits. Both devices have essentially unlimited life.

1 Chopper for Direct-Current Motor

Frequently the control for a dc motor is termed a chopper, since it connects the battery to the motor intermittently. As explained above, the rapid interruption is timed to achieve the desired average voltage. A number of different schemes are possible: some use a fixed on-time with variable off-time, while others use a variable on-time and a fixed off-time, still others use a combination of these two. In general, it is desirable to operate at the highest possible chopping frequency so as to minimize the fluctuation of current, some compromise must be made, however, to reduce switching losses.

The chopper is not only much more efficient than the switch resistor type, but it also permits very exacting control of current. This, in turn, permits continuous, stepless torque control. Probably more important, the current can be limited to protect the motor and the solid-state controls themselves, with proper current limiting, high reliability can be expected from the chopper and motor. For example, if maximum torque is required from the motor, the current limit can be set at, say, twice rated motor current. This will enable the motor to deliver approximately twice its rated torque. Both the motor and control should be designed to withstand this current for perhaps 5 minutes, in this way, both the motor and the control are protected even if the motor is stalled.

The 5-minute rating of the motor is an arbitrary figure. It could be designed to be 1 or 2 minutes or even 10 minutes. The particular design will depend upon the overall system efficiency, weight, driving pattern, etc. However, the solid-state component in the chopper must be capable of carrying the overload current continuously, since its overload capability is extremely limited. Most of the other components in the chopper, except those that have a thermal storage capacity, must also be able to carry the overload current on a continuous basis.

In principle, the efficiency of the controller can be extremely high, since the process is basically lossless. However, when the SCR is carrying current, it exhibits a 1-volt drop, which when multiplied by the current gives the forward conduction loss. In addition, there are switching losses, blocking losses, and losses associated with the free-wheeling diode that closes the motor on itself during the times that the SCR blocks the current from the battery to the motor. Other losses are associated with the turnoff capacitor and its associated charging circuitry.

The efficiency of the chopper is greatly affected by the voltage of the system, because conduction loss due to the 1-volt drop is relatively less at higher voltages. Considering this loss alone in the case of a 12-volt system, the efficiency cannot exceed 92%. When the other losses are included, a rather low overall efficiency would result. Therefore, it is essential to use a high system voltage.

High voltage is important not only for increasing efficiency, but also for reducing the weight of the chopper. The physical size of the solid-state components is dependent upon the current and is unaffected by the voltage. This independence of voltage does not hold for the capacitive and inductive components in the chopper, however, their size and weight are in general related to the power handled and also to the precise design of the chopper.

As a rule, it is best to use as high a voltage as possible to reduce the magnitude of the current. To keep the rated current below 100 amperes and hence the overload current below 200 amperes, it is necessary to use voltages of the order of 150-500V for the range of vehicles studied. For these voltages the weights which should be achievable are shown in Figure 9. These weights assume fan cooling of the choppers, which is possible because of their high efficiencies (90% or more). Heavy contactors and circuit breakers should not be necessary, because of the current-limiting capability of the chopper.

Considering the small size of the chopper, it might be feasible to attach it directly to the motor housing. In this way, dissipation of heat from the solid-state power handling components could be increased, and heavy-current carrying terminals could be avoided. This concept is analogous to the incorporation of silicon diodes within the housing of present automobile alternators.

Although the basic principle of the chopper is well understood, the device has only recently been applied to experimental fork lift trucks, delivery vans, and other vehicles. The technology is available, but it will require a great deal of development to bring the chopper from a promising concept to readily available equipment for electric vehicles.

The present manufacturing cost of a chopper control is about $20 per vehicle horsepower. However, considering the actual material costs and the fact that the manufacturing processes lend themselves to automation, an order-of-magnitude reduction to $2 per horsepower would appear to be reasonable.

All the logic functions associated with the timing and control of the chopper could be done with microelectronic integrated circuit modules. These are incredibly small and can perform many control functions at an extremely reasonable cost. Therefore, it would seem that a great deal of ingenuity and development should be directed toward applying chopper technology to a mass-produced, reliable, low-cost product.

To accomplish regenerative braking, all that is necessary is a slight rearrangement of the basic power handling component and a small amount of additional logic. Regenerative braking is only beginning to make an appearance in chopper circuits, and much innovation is needed, e.g., through appropriate current sensing and making the circuit changeovers at current zero, it would be possible to do away with all the large contactors or dc current interrupters which are frequently incorporated in choppers.

Highly efficient regenerative braking can permit the return of power to the battery. The amount returned depends upon the driving power of the vehicle as well as circuit design and efficiency. For vehicles such as buses that make frequent starts and stops, it has been

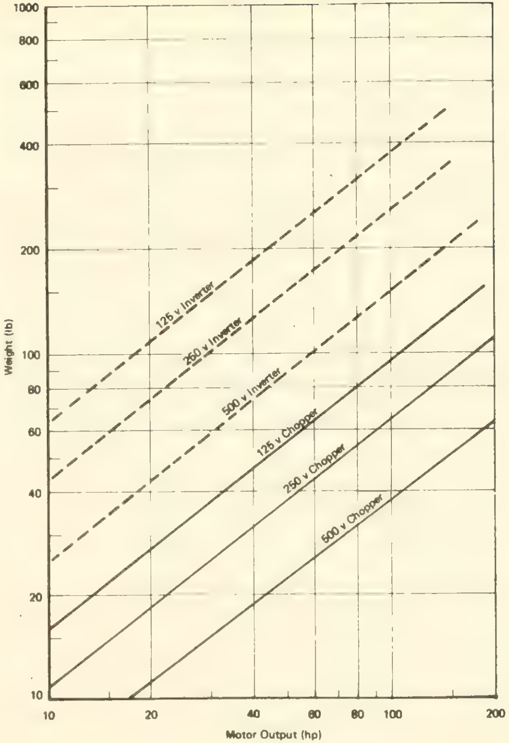

FIGURE 9 WEIGHT OF CONTROL UNIT

reported that the saving in power can be as much as 30%. For vehicles that use a more normal driving pattern, however, the energy saving is not large enough to justify the cost of adding this feature.

Regenerative braking does not make conventional brakes unnecessary, for it is of little use at low speed, most of the power is returned during the initial period of deceleration.

2. Inverter for Induction Motor

When an induction motor is used as a propulsion means, an inverter is used as the control for varying its torque and speed. An inverter takes dc power from the battery and changes it to ac power of the appropriate voltage and frequency, thus, it combines the voltage-adjusting function of the chopper with an ability to vary the frequency as well

Inverters using SCR's for driving induction motors over wide speed ranges are relatively new. They are just coming onto the market for industrial variable-speed drives and have been used with a few experimental electric vehicles.

As with the chopper, power SCR's are used in an inverter to connect the three motor windings to the battery on a time-varying basis. In essence, at least three choppers are required, one for each of the three phases of the motor, because each phase must be cyclically energized and each carries the same peak current In practice, it is often convenient to use essentially six choppers, each capable of delivering half the required voltage. As with the chopper, the peak current is the limiting factor in design

In addition to all the components associated with a chopper, a large bank of capacitors must be placed across the dc input This results from the fact that reactive power must be handled by the inverter A further component which must be added is a special speed-sensing tachometer. A signal from this tachometer is used to determine the frequency of the inverter.

The size and weight of an inverter are typically about three times those of a chopper of equivalent power and voltage, excluding the capacitor bank across the dc input The estimated weights are graphically shown in Figure 9 as a function of voltage and power A manufacturing cost of $5 per vehicle horsepower should eventually be possible, again excluding the capacitor bank and tachometer.

The fact that the inverter has a more complex logic requirement than the chopper should not increase the ultimate cost; specialized integrated circuits would be developed for vehicle inverters to accommodate all the complex functions As in the case of the chopper, current limiting is essential and must be applied with instantaneous control to protect both the inverter and the motor, as well as to provide torque control.

If regenerative braking is considered justified by the application, it can be incorporated within the inverter at a slight increase in cost by using the motor as an induction generator This does not require that the solid-state components be shifted around, as in the case of the chopper circuit, but only that additional logic be incorporated

To protect both motor and inverter, the controlling of the SCR's must be timed so as to limit the rate at which power is returned to the battery

3. Static Commutator for Synchronous Motor

As with the induction motor, the speed and torque of a synchronous motor are controlled by varying both the voltage and the frequency of the power supplied However, the control for a synchronous motor differs somewhat from an inverter. it is called a static commutator for purposes of distinction as well as to indicate its functional relation to the copper bar commutator of a conventional dc motor. The commutator and brush assembly of a dc motor in effect chop the dc input into variable-frequency power for the motor windings, when this is accomplished by a separate static commutator, the roles of stator and rotor can be interchanged This permits a large reduction in the current that the slip rings must carry, because the current in the rotor of a dc motor is much larger than that in the stator

The power circuit of the static commutator is identical to that of the inverter, except that it needs no capacitor bank across the dc supply However, the control of the SCR's is somewhat different the position-sensing tachometer attached to the motor determines which windings should be energized at any given moment The tachometer can take a number of forms, experimental arrangements have been employed using photoelectric detectors, Hall detectors, and reluctance detectors The information from the position sensor is used to control the main power SCR's.

The size of the static commutator is about the same as that of the inverter The weights given in Figure 9 and the cost of $5 per vehicle horsepower also apply for the basic static commutator, to these figures must be added the small weight of the tachometer and its associated cost

C. SPEED REDUCERS

To couple a high-speed motor to the wheel, a speed reducer with a relatively large reduction ratio is needed For railroad traction, a gearbox with a low reduction ratio is used. these are very rugged but heavy units At the other extreme, very lightweight gearboxes have been developed for torpedo propulsion systems, but these are designed for short life and thus are not suitable for vehicular use It would seem that a compromise between these two technologies would lead to a gearbox with the desired reliability and light weight.

The large experimental electric vehicles built to date have used planetary gearboxes that are directly connected to the motor and employ oil cooling This is a lightweight arrangement particularly suited to motors of relatively high horsepower.

Another solution is the "motorized wheel," in which the motor and gear reduction unit are incorporated in the hub of the wheel This compact arrangement is now used in some earth-moving equipment and might be well suited to large vehicles like buses.

On small experimental electric cars, double timing belts have been used to achieve relatively high speed-reduction ratios Belt drives are an extremely lightweight and inexpensive means for coupling the motor to the wheels

In view of the mature technology of speed reduction devices, adapting one or more of these approaches should not be difficult The principal task is to make a detailed analysis that will indicate which offers the lowest cost and best arrangement. For the small utility car. which would use air-cooled motors of rather low power, the multiple timing belt approach seems desirable. for the bus. the oil-cooled gearbox or possibly the motorized wheel might be preferable

D. COOLING REQUIREMENTS

The heat losses which occur in the motor. the speed reduction unit, and the control unit must be removed by a cooling system Air cooling, which is the simplest method. requires a constant-speed blower and duct arrangement The more elaborate oil-cooling system requires an oil pump. heat exchanger. and other components. In both cases. the heat to be rejected would be used to warm the passenger compartment during the winter and discharged to the surroundings in warmer weather The motor may have to operate for sustained periods at extremely low speed. so it cannot be used to drive the cooling system. the system must be separately driven.

V. ELECTROCHEMICAL POWER SOURCES

This section contains a review of the present state of the art of those electrochemical power sources, batteries and fuel cells, which have prospects of application as the prime power source in electric vehicles, together with some prognosis of their future development Consideration is also given to the possibility of hybrid electrochemical systems consisting of battery-battery and fuel cell-battery combinations (The possible application of batteries in mechanical-electrical systems is covered in Section VI) The review of electrochemical power sources is organized into four subsections covering conventional batteries, batteries under development, fuel cells, and electrochemical hybrid combinations

A. CONVENTIONAL BATTERIES

1. Lead-Acid

The lead-acid battery is the oldest of the secondary battery systems and has been in existence for over 100 years It is also the most important system economically, accounting for about 80% of the more than $500 million annual sales of secondary batteries in the United States. While the largest proportion of these sales is for the specific application of starting, lighting, and ignition (SLI) in vehicles powered by internal combustion engines, a substantial volume is used as the power source for non-highway electric vehicles such as fork lift trucks, golf carts, and mine locomotives

SLI batteries are designed for float service with occasional high power discharge and are not suitable for traction service, which involves repeated deep discharge cycling Batteries for traction applications have thicker plates and are generally of more rugged construction. Their delivered energy density is now in the range of 10-14 w-hr/lb While high power drains cause a decrease in delivered energy, power densities of as much as 35 w/lb can be sustained for short periods

The major virtues of the lead-acid system are its high degree of reliability (a typical lifetime of four to six years in traction service under a continuous daily cycle of full charge and discharge) at low cost (OEM prices approximate $0 25/lb for SLI and $0 50-0 60/lb for traction type batteries) While these virtues make lead-acid today's most important practical battery system for electric traction,* its low energy density eliminates it from consideration as the primary energy source for almost all of the six classes of vehicles under consideration in this study The sole possible exception is the utility car with lightweight construction, the specifications for which are close to the upper limit of the lead-acid battery's technical capabilities

The question arises as to the potential for improvement in the lead-acid system Incremental advances in energy density are certainly possible, and in fact there has already been a substantial improvement (of the order of 30%) in these parameters over the last 15-20 years and this is expected to continue For example, a major U S manufacturer is about to introduce a new industrial battery with an energy density of 16 w-hr/lb at a ten hour discharge rate These advances have primarily resulted from the utilization of lighter, stronger materials for cases, improvement in the design of the plates, new grid alloys, more porous and durable separators, etc Somewhat more radical changes are being worked on by a group in England (U.K Electricity Council Research Centre), which is investigating improvements in capacity that might result from pumping electrolyte through the battery plates, although the extra complexity may make the scheme unattractive Some publicity has been given in the United States to the use of traces of cobalt salts in the electrolyte to improve energy density (Electric Fuel Propulsion, Inc , see also Appendix A) The presence of cobalt in closely controlled proportions can lessen grid corrosion, thereby permitting the use of thinner plates and yielding a higher energy density, it does, however, increase the rate of shedding of active material from the plates, thus shortening battery life

With regard to power density, the maxima achieved in today's conventional lead-acid batteries are only moderately below the demands of the vehicle types as listed in Table 1 Operation at high power density does lower the energy storage capacity of the battery, however, and rapid charge and discharge raises the internal temperature of the battery and tends to shorten its life An interesting recent development is that of a high rate lead-acid battery for pulse discharge and having "pile type" construction This battery, being developed by Gould-National Batteries, Inc for the U S Navy Electronics Laboratory, has a power density of around 60-70 w/lb and might possibly find application in hybrid electrical vehicle systems (see Sections IV-D and VI)

Thus the limitations on its energy density would seem to preclude the large scale use of lead-acid batteries as a prime energy source for highway vehicles Much wider use of these batteries, based on their low cost, rechargeability, and availability is, however, foreseen for such applications as transportation within industrial plants, hospitals, airports, resorts, and off-highway shopping centers and communities Anticipated advances and cost improvements in motors and control systems will also benefit electric vehicles used for these purposes

2. Nickel-Cadmium

The salient technical features of the nickel-cadmium battery are its excellent service life, an energy density of 12-14 w-hr/lb, which is closely comparable to that of the lead-acid battery, and a power density which in certain constructions can be as high as 300 w/lb There are two major types of nickel-cadmium batteries those with pocket plates, which have cycle lives in excess of 3000 or so and those with sintered plates, whose cycle lives are less than half as great but which have very high power densities Because of its low energy density it is, like the lead-acid system, outside the scope of our primary power source specifications for electric vehicles, except perhaps for the small utility vehicle Its high power density however makes it an attractive prospect on technical grounds for various types of hybrid power source as will be discussed in Sections V-D VI and VII This is especially true of the 'bipolar' nickel-cadmium battery developed by Gulton Industries Inc for high discharge rate applications This battery has very thin sintered plates attached to thin metal sheets which act as the connectors between adjacent cells The thin electrode design permits the achievement of power densities of around 300 w/lb

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* The extensive history of lead-acid battery use in highway vehicles, particularly in the United Kingdom, is reviewed in Appendices A and B

The nickel-cadmium battery has not been used in traction applications, except to a limited extent in lift trucks in Continental Europe and in a demonstration automobile in Sweden (Appendix B). The major drawback is its cost, which on a per pound basis is about five times that of the lead-acid traction battery. Since a significant part of these costs derives from the costs of nickel and cadmium, they are unlikely to fall sufficiently to change the nickel-cadmium battery's competitive position A further argument can be raised against cadmium on the grounds of availability supplies of the element are not great enough to support a major application in electric vehicles, and since it is a by-product of lead and zinc, its production cannot be economically expanded for its own sake Thus the nickel-cadmium battery in any form seems unlikely to play a major role in electric vehicle development.

3. Nickel-Iron

The nickel-iron system has an energy density slightly lower than those of nickel-cadmium and lead-acid and a lifetime which can be measured in decades It is also a very rugged battery, capable of withstanding much physical and electrical abuse Its power density, however, is not as great as that of the nickel-cadmium system, and because of the smaller volume of production and the processing costs involved, its price structure is not significantly lower The major reasons why the nickel-iron battery has not found greater general application are its poor charge retention and low electrical efficiency in charging, both of which characteristics lead to excessive gassing and a high maintenance requirement Although it has found some acceptance in European lift trucks and in U S mine locomotives, the low energy density of the system gives it little relevance as a potential power source for electric highway vehicles.

4. Silver Batteries

There are two secondary batteries which use silver oxide cathodes: the silver-zinc system and the silver-cadmium system The former battery has a high energy density amounting in certain configurations to about 60 w-hr/lb, and an excellent power density of as much as 200 w/lb, properties which on technical grounds would appear to make it a significant contender for many electric vehicle applications. It has, in fact, been used recently in certain experimental electric vehicles, most notably the GM "Electrovair" and the Yardney Electric converted Renault Dauphine (see Appendix A) However, the cycle life at full discharge seldom exceeds 40-50 cycles, and the high cost and relative scarcity of silver rule it out for large scale use The 500-lb battery in the Electrovair II was reported to cost some $15 000, or $30/lb, and about 30% of the packaged weight is accounted for by silver, which now has a raw material cost of about $35/lb. Yardney Electric has suggested that the silver might be leased, but the poor cycle life is a difficult problem and lack of availability unsurmountable Its use therefore seems likely to be restricted to demonstration vehicles and test bed evaluations.

The properties of silver-cadmium batteries are in many ways intermediate between those of nickel-cadmium and silver-zinc batteries Their energy density of about 25 w-hr lb and their high power density comparable to that of silver-zinc batteries make them marginal candidates from a technical standpoint for certain of the vehicle applications listed in Table I However as with silver-zinc, high cost and insufficient availability of materials eliminate them from serious consideration for large scale use

B. BATTERIES UNDER DEVELOPMENT

The technical parameters of the conventional batteries described in the previous subsection clearly fall short, particularly in energy density, of the requirements specified in Table I Since conventional batteries use materials with relatively high equivalent weights, an obvious route to improvement lies in the use of reactions which have higher energy release and employ active materials of low equivalent weight The source of energy in all batteries is the oxidation-reduction reaction which takes place between the active materials of the positive (cathode) or oxidizing plate and the negative (anode) or reducing plate The energy released, corresponding to the weights of these active materials alone can be calculated and sets an upper limit for the energy density of a given battery system In practice, when the weights of case, grids, separators, electrolyte and supporting structures are considered the practically attainable energy density is only some 10-20% of this theoretical maximum Nonetheless, it is evident that the higher the energy release in the cell reaction, the higher the energy density of the resulting battery

Prime candidates for use as anode materials in high energy density batteries are the alkali metals in particular lithium and sodium Their very reactivity however, imposes some severe restriction on their mode of utilization They cannot be used with conventional aqueous electrolytes, because of the rapid direct chemical reaction, their use is possible only in combination with nonreactive electrolytes in particular molten salts and organic liquids The former introduce the complication of a high operating temperature and, in many instances, severe problems in materials selection, while the latter tend to be hampered by low electrolytic conductivity, poor shelf life, and cathode polarization problems, which limit their power density

The other major approach to improvement in energy density is the use of atmospheric oxygen as the cathodic oxidizing agent The weight of the cathode in the battery is then limited to that of a catalytically active oxygen electrode the oxidant (air) being available in limitless amount with no weight penalty

Power densities are a reflection of the kinetics of the various electrochemical reactions taking place in the battery They can be improved by attention to certain physical factors particularly the surface area of the electrode and are increased at elevated temperatures For this latter reason the molten salt systems are particularly favored for applications involving high power density

This subsection reviews the status of the work presently under way on improved battery systems for use in electric vehicles

1. High-Temperature Alkali Metal Batteries

a Lithium-Chlorine

The battery with the highest potential energy density of those now under investigation is based on lithium and chlorine as reactants and is being developed by the General Motors Corporation Its theoretical energy density is approximately 1000 w-hr/lb, and it has an open circuit potential of 3 5 volts In its work to date, GM has demonstrated the cell's capability for generating very high current densities on the order of several thousand amperes per square foot

The principal liabilities of the lithium-chlorine battery are the difficulties associated with storing chlorine gas under pressure and at temperatures of around 650°C, and the tendency of the cell to self-discharge The first problem is being tackled by using highly adsorbent charcoal to reduce the pressure of the stored chlorine This approach seems quite successful, although a great deal more needs to be learned about the cycling capability of charcoal in this application.

While its electrochemical characteristics are very encouraging, the lithium-chlorine battery presents many novel and extremely challenging problems in materials engineering, and extensive development will clearly be needed before the system can be made practical The question of hazards arising from the storage of chlorine gas under pressure and at high temperatures seems, at this stage at least, likely to limit the chances of such a battery's being adopted as a power source for vehicles

It is not possible to make any accurate estimates of the effective energy and power densities, still less the costs, to be expected for the lithium-chlorine battery Much depends on the complexity of the safety engineering and packaging that would be necessary It seems likely, however, that the system will easily possess the technical capabilities required to satisfy the most exacting of the electric vehicle's specifications

With regard to costs, a theoretical minimum quantity of about 25 pounds of lithium would be required for a battery capable of meeting the requirements of the family car At today's price for lithium, $7/lb, this corresponds to $175. The actual quantity of lithium needed might be half as much again as the 25 pounds, but with anticipated lower production costs of the metal in quantity the resulting materials cost for lithium might not be much more than $100 While this is a significant item, it would not appear to rule out the system from further consideration

Maintenance of the operating temperature is a problem with all high-temperature battery systems In a well-insulated system, the self-discharge rate is usually sufficient to maintain temperature However good insulation tends to be an embarrassment when the battery is working at high power levels, either on charge or on discharge, since the excessive amount of heat generated causes an undesirable rise in the internal temperature. On the other hand, if the battery is to be shut down for long periods, it seems essential that some kind of built-in combustion heater be included in the system.

b Sodium-Sulfur

Another approach to the use of alkali metals in high-temperature batteries is being taken by the Ford Motor Company Ford's cell uses sodium and sulfur as the reactants, and the electrolyte is a special ceramic material permeable only to sodium ions The properties of the ceramic are critical for the effective functioning of this battery While the sodium-sulfur battery does not have the theoretical energy density of the lithium-chlorine system (300-600 w-hr/lb, depending on the extent of the reaction, versus more than 1000 w-hr/lb), it does have two major practical advantages First is the lower temperature of operation, approximately 300°C. At this temperature, sulfur is a liquid, and containment of the cathode materials thus presents far fewer engineering problems than in the lithium-chlorine system The second advantage is that the battery reactants, sodium and sulfur, are both extremely abundant and very inexpensive, there are thus no immediate and fundamental reasons why the battery might not eventually develop into a low-cost power source for large-scale use

Since Ford's work is proprietary, relatively little specific information is available Present efforts are apparently confined to experiments with single cells, the goals being to determine the factors affecting electrical efficiency and cycle life and to find solutions for the various engineering and materials selection problems which are encountered Since multi-cell work is bound to raise a whole new series of problems concerned with design and with maintenance of the electrical balance of cells in the battery, it is not possible to make an accurate prediction of the time scale for the development of this battery into a practical power source for vehicles

c Capacitive Storage

A third approach to high-temperature battery development has been taken by the Standard Oil Company (Ohio) SOHIO's work was originally based on the use of carbon electrodes with very high surface areas to provide capacitive energy storage All electrolyte-electrode interfaces have double layer capacitances, however these are in general quite small and do not store significant quantities of energy In the case of porous carbon electrodes, the internal surface can reach huge values, and the amounts of energy that can be stored capacitively become comparable with those stored in a battery of equivalent weight Electrolytic condensers with capacities of the order of farads can be set up by immersing porous carbon electrodes in an aqueous electrolyte such as sulfuric acid A very substantial enhancement in capacity and hence in the capability for energy storage, can, however be obtained by using a molten salt electrolyte A further bonus comes from the much higher breakdown voltages of these electrolytes, which permit the cells to be operated at levels of 3 volts or more, compared with a maximum of 1 8 volts or so in aqueous systems Since the energy storage is proportional to the square of the voltage this means a substantially greater energy density

In practice, the SOHIO device, which contains a molten potassium chloride-lithium chloride eutectic as the electrolyte does not behave as a pure capacitor It was found preferable to substitute aluminum for carbon at the negative electrode (to reduce self-discharge, due to lithium solubility), and the lithium enters the aluminum interstitially. At the positive electrode it seems likely that the chloride ion is at least partly discharged but is adsorbed very strongly on the carbon and so never appears as a gas The system may thus be partly a capacitor and partly a special type of lithium-chlorine battery in which the active materials remain within the current collectors The fall-off in voltage as the cell is discharged is intermediate between those typical of batteries and capacitors

At its present stage of development the SOHIO device appears to be capable of attaining an energy density of 50 w-hr/lb and a power density of 150 w/lb in its packaged condition. Experimental batteries with 30-kwh storage capacity are now being designed. Thermal insulation is provided by a vacuum container which will maintain operating temperature for 40 hours without auxiliary heat The self-discharge rate is low, taking approximately 20 days from full charge. While the SOHIO battery seems likely to have inherently lower energy densities than those of other types of high-temperature systems, with improvements in the technology of the carbon cathodes, its energy density might eventually be raised to about 100 w-hr/lb. Estimates of cost are necessarily very tentative because of the novelty of some of the fabrication processes, but it appears that in large-scale production they might approach a level of $1 50/lb Preliminary indications are that the lifetime will be about three years With a pilot manufacturing plant going into operation SOHIO's battery seems to be most advanced of the high-temperature systems now under development

d. Lithium Cells With Tellurium, Selenium, and Other Non-Metals

Other types of high-temperature cells involving lithium anodes and molten nonmetallic elements as the cathodes are under investigation at the Argonne National Laboratory The electrolyte is a relatively low melting ternary eutectic mixture of lithium fluoride, chloride, and iodide made into a solid paste by the carefully controlled addition of micron sized particles of lithium aluminate The majority of the work has been focused upon the lithium-tellurium and lithium-selenium couples, the cell reaction resulting in the formation of lithium telluride or selenide, which remains dissolved in the molten cathode Operating temperatures are necessarily above those of the melting points of the cathode elements and are in the 470-500° C range for lithium-tellurium and 350-400° C for lithium-selenium.

The great virtue of these systems is the extremely high degree of reversibility of the electrode reactions and their capacity for sustaining current densities of approximately 10,000 amperes per square foot Polarization of the cells is very low and entirely accounted for by internal resistance The major constructional material is Armco iron and corrosion is apparently no great problem Projections based upon the behavior of single cells having an electrode area of 10 square centimeters indicate that the packaged energy densities would be 90 w-hr lb for Li/Te and 120 w-hr/lb for Li/Se Power densities are very high 200-500 w/lb for Li/Te and 300-600 w/lb for Li/Se

Probably the greatest handicap to the development of these cells for vehicle applications is the cost and relative scarcity of the cathodic elements Because of this some preliminary experiments were carried out in recent months with a lithium-phosphorus cell, but the necessity of working above the melting point of red phosphorus requires operating temperatures above 600°C, and the observed voltage of the cell is only about 1 volt versus 1 75 volts for Li/Te and 2 4 volts for Li/Se. This initial work with phosphorus has therefore been unpromising The most recent work has been with the lithium-sulphur system and has been very encouraging as far as it has gone This system appears to have great promise as a vehicular power source

Sodium cells are not of interest because of the higher melting points of the sodium salt electrolytes and the greater tendency of sodium to dissolve in the electrolyte

2 Alkali Metal Batteries With Organic Electrolytes

The use of nonreactive organic liquids as electrolytic solvents in alkali metal batteries permits ambient-temperature operation and thus avoids many of the difficulties associated with molten salt and ceramic electrolytes It has its full share of disadvantages, however since for a variety of reasons, organic liquids are inferior electrolytic solvents

A great deal of work has been done over the last five years, much of it supported by NASA on the selection of cathodes and organic electrolyte combinations for use with lithium anodes in primary batteries The major problems have been the identification of non-aqueous electrolytic solvents compatible with lithium and having sufficiently high conductivity, and of cathode materials capable of sustaining even very small current densities without extremely high polarization. Some progress has been made, although the best of these systems can support current densities only 5-10% as great as those possible in conventional aqueous batteries

The development of rechargeable systems is at an even earlier stage In work carried out some three or four years ago, the Lockheed Aircraft Company demonstrated the rechargeability of a lithium-silver chloride battery having a lithium perchlorate-propylene carbonate electrolyte. The best of these cells showed some 40 or 50 cycles of operation at almost 80% discharge before the capacity fell off significantly This system was not developed further, because the high equivalent weight of the cathode gave it no substantial advantage in energy density over many aqueous systems Other attempts at recharging organic electrolyte batteries have encountered severe problems with lithium plating and with the recycling or solubility in the electrolyte of the cathode materials (generally halides or sulfides of transition metals)

More recently, Gulton Industries, Inc has engaged in the development of a rechargeable lithium-nickel fluoride battery having a potassium hexafluorophosphate-propylene carbonate electrolyte Claims have been made that this battery system has the potential to attain a packaged energy density of 150 w-hr/lb and a power density of 20-30 w/lb, however, the published technical information* shows that achievements to date fall short of these goals. On repeated cycling a nominally 0 025 amp-hr cell discharged for 8 hours at 20 ma (the current density at the electrodes being 0 1 ma/cm^2) showed a voltage decrease of from 3.0 to 1.4, the value at the midpoint being 1 75 volts If these conditions are typical, then a 13-amp-hr cell which apparently weighs 0.55 pound would deliver 27 w-hr/lb, or approximately 40 w-hr/lb if the cell were discharged completely High discharge currents have been reported, but only for pulse conditions of perhaps a few milliseconds The falloff in voltage at a steady discharge current density of only 0 1 ma/cm^2 indicates that high power densities are unlikely to be attained under sustained conditions A five-hour discharge rate may well be the practical limit for this type of battery.

Gulton has had more success than other groups in recharging lithium non-aqueous batteries, but even so they have found it necessary to use low current densities and very thin coatings of active material on the current collector to achieve significant cycle life The latter requirement, of course, tends to decrease the energy density of the cell

As a class, rechargeable alkali metal batteries with organic electrolytes seem a long way from practicality for vehicle use Their difficulties derive from fundamental electrochemical problems which even in comparison with the engineering problems faced by the high-temperature batteries, could take a long time to resolve. Gulton Industries, however, is optimistic about their prospects and has entered into a vehicle development program with American Motors Corporation (see Appendix A) to use its battery with a high-rate nickel-cadmium battery in the hybrid power source described in Section V-D The long-term cost estimates for the lithium battery have been estimated to be in the range of $4 - 5/lb.

The Electrochimica Corporation has also advocated the use of organic electrolyte lithium batteries in electric vehicles Its work has been concentrated on a lithium-copper fluoride system, and claims are made that this system has particularly high current densities for this class of battery Lacking specific information, we cannot make a detailed assessment of the system It is not claimed to be rechargeable, however, and therefore is not yet at a stage for consideration in vehicles

3. Metal-Air Batteries

The employment of air cathodes represents another general approach to the development of batteries with higher energy density In most programs in this area, aqueous electrolytes have been used in combination with relatively conventional metal anode materials The concept is not new, low-rate zinc-air primary batteries have been available for more than half a century The novelty in the recent work is in the use of air cathodes capable of supporting very much higher current densities than those of the conventional cells, an advance derived from fuel cell technology

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* H N Seiger, S Charlip, A E Lyall, and R C Shair, *Organic Electrolyte Batteries*, paper presented at 21st Annual Power Sources Conference, Atlantic City, N J., May 16-18, 1967

The electric vehicle application requires rechargeable batteries, which present additional problems to air-cell technology Problems arise with the rechargeability of the anode and with the oxidation resistance of the air cathode, which has to withstand oxygen evolution or be supported by an auxiliary third electrode for recharging The work on zinc-air cells is hampered by the cla[illegible]fficulties of recharging the zinc electrode, of which dendrite growth is the most [illegible]ant. The following paragraphs review the present activities in metal-air battery development

a. Zinc-Air (General Atomic)

One of the most prominent of the programs on zinc-air batteries is that being conducted at General Atomic, now a division of the Gulf Oil Corporation The work is supported in part by the Edison Electric Institute, and the British company, Joseph Lucas Ltd., has become a partner in the program. The basic approach taken is to avoid the dendrite growth problem by pumping the electrolyte over the surface of the electrode The technique is very effective but results in considerable engineering complexity On discharge, the reaction product, zinc oxide, is swept out of the cell and stored separately, being fed back in again on charge. The cathode is of sintered nickel with a palladium catalyst, and air is forced through it with a compressor The system appears to have a near-term energy density capability of 50-60 w-hr/lb and a power density capability of 30-35 w/lb These figures are net after subtracting the parasitic power load for pumps, compressors, and other auxiliary equipment This latter drain is estimated at a fairly constant 15% of gross power output in the size range of greatest interest, 20-80 kw

The largest modules built to date have been sized at 15 kwh, 4-5 kw at 36 volts, and they will be used to determine the performance of the system on extended cycling A full charge can be completed in about two hours If the system is not abused electrically, it would appear to have a cycle life comparable to that of the lead-acid battery Carbon dioxide contamination of the electrolyte is a problem but may be dealt with by changing the electrolyte occasionally perhaps with the same frequency as oil is now changed in a gasoline engine.

Realistic estimates place the cost of the General Atomic battery in the range from about $1.50/lb for one designed with good energy storage but only limited power capability to about $3 30/lb for one with the highest power density of which the system is capable At present, the major objective of General Atomic's project is the electric lift truck application

b. Zinc-Air (Leesona)

The Leesona Corporation is also very active in metal-air battery development. While much of its effort is in the primary zinc-air field, it is also investigating electrically rechargeable secondary battery systems. It has developed a mechanically rechargeable zinc-air battery, which is now being delivered to the Army and Marine Corps The latter battery, which is designed as a power source for military communication systems, is far too costly to consider as a vehicular power source. Even if anode costs were simply those of the materials, with a credit for the discharged anode, mechanically rechargeable systems would still appear to be several times too expensive for consideration in vehicles.

The work on secondary zinc-air batteries at Leesona is based on configurations which are similar to those of the company's primary metal-air batteries Much of its effort is directed at improving separators, both organic and inorganic, Leesona is a licensee of the inorganic separator developed by the Astropower Laboratory of McDonnell-Douglas, Inc (see below) Leesona is also investigating the effect of close control of charging current density and pulse charging in attempts to solve the problem of dendrite growth

The Leesona primary zinc-air battery delivers as much as 116 w-hr/lb in radio service and can sustain steady discharge at a power density of 18 w/lb. Such favorable parameters are unlikely to carry over to electrically rechargeable secondary systems, where good cycle life is possible only when the battery is not completely discharged.

The future costs of Leesona's electrically rechargeable zinc-air battery, manufactured in quantity, can only be guessed, because so much depends on the quantities and costs of catalysts required for the cathode and the degree of complexity in the battery structure; a figure of $1.50-$2.00/lb might be reasonable. It is generally agreed that the technical problems associated with such cells are far from being solved and their introduction lies in the indefinite future.

c. Sodium-Air

An interesting variant on metal-air batteries – one which permits the use of an alkali metal anode – is the sodium-air battery being developed by the Atomics International Division of North American Rockwell Corporation. Each cell of this battery is essentially two cells: one is a sodium-sodium amalgam cell with a molten salt electrolyte, and the other is formed by the sodium amalgam with an air cathode in an aqueous sodium hydroxide electrolyte. The system is made feasible by the development of a very low-melting eutectic sodium salt mixture as the electrolyte for the sodium-sodium amalgam cell, in which the sodium ion is the sole current-carrying species Because of the low melting point the temperature of operation is not much above 100°C, which is quite compatible with the operation of the sodium amalgam-air cell.

The sodium-air battery is still at an early stage of development. Experience with it is limited to prototype models which generate about 25 watts and which have completed about 50 operating cycles The air cathode, which has not been optimized, is a modified form of an American Cyanamid electrode containing about 10 milligrams of platinum per square inch. The relatively low temperature of operation permits the use of plastics, particularly polypropylene, as materials of construction. The molten salt electrolyte is contained in a porous alumina disc in some designs and is unconstrained in others.

Projections based on extrapolations from early results indicate that energy densities for a 20-kw battery would be in the range of 100-150 w-hr/lb and power densities would be 25-35 w/lb, with ultimate capabilities significantly higher than these figures. The power densities are however, based on current densities that may necessitate uneconomically large quantities of platinum in the air cathodes.

In addition to the platinum, mercury is also a major material cost Overall manufacturing costs for the battery on a large scale are estimated at being in the $1.50 to $2.00/lb range, which is similar to those projected for many of the high-temperature batteries. The cost related to the engineering complexity of the sodium-air cell is offset by the use of economical plastic materials in its construction.

From the operational standpoint the sodium-air concept has a number of attractive features for possible application as a vehicle power source It has a much lower temperature of operation than the other alkali metal-molten salt systems, and its power density is likely to be higher than those of the organic electrolyte batteries Moreover, it retains the molten anode feature and thus avoids the difficulties of dendrite formation on recharge. A further consequence of the molten and thus structureless anode is that mechanical rechargeability is more likely to be economically feasible than with other types of metal-air battery.

On the negative side, the cell appears to be rather complex, and operating experience with it is limited The long-term stability of the low-melting eutectic mixture may be a questionable feature, but the self discharge rate at the sodium amalgam-sodium hydroxide interface is apparently low.

Atomics International has recently formulated a design in which the two cells of the battery are constructed as separate entities and the sodium amalgam is pumped between them. While this would require somewhat greater quantities of mercury, cell construction would be simplified, reliability would be enhanced, and it is predicted that overall costs would be reduced

d. Other Metal-Air Batteries

In addition to the work reviewed above, there is a great deal of other activity in the field of rechargeable metal-air batteries. On the basis of the little information that has been published, none of it appears to be at a more advanced stage than the programs already described. Union Carbide and ESB, Inc are working on electrically rechargeable zinc-air systems generally similar to that of Leesona Yardney Electric Corporation, in a program partly sponsored by the Ford Motor Company, is developing its "Rotoxel" zinc-air cell in which dendrite formation at the zinc anode is prevented by rotating the zinc anode against a doctor blade this cell uses silver catalysts at its air cathode The Astropower Laboratory of McDonnell-Douglas Corporation is also investigating rechargeable zinc-air cells, making use of its novel inorganic separator developed originally for heat sterilizable silver-zinc batteries, this separator is reported to achieve a significant reduction of dendrite growth on zinc during recharge

Globe-Union Inc , in a program sponsored by the U S Army Electronics Command is investigating a lithium-moist air battery in nonaqueous solvents While this might represent the ultimate in theoretical energy density for metal-air cells the practical difficulties appear to be overwhelming.

General Telephone and Electronics has a program on the iron-air battery. In view of the maturity of the technology of rechargeable iron electrodes, this might be a promising approach.

Zaromb Research Corporation is investigating aluminum-air cells, but in spite of their attractive theoretical energy densities, they are relatively unpromising. Less than half the theoretical voltage is obtained, leaving the rest to appear as heat. As the aluminum electrode cannot be recharged electrically, the system can be considered potentially rechargeable only on a mechanical basis. The General Electric Company has developed a mechanically rechargeable magnesium-air battery conceptually similar to the Leesona zinc-air system but has not advanced it as a possible vehicle power source. General Electric is also investigating rechargeable cadmium-air systems, as is Union Carbide. These latter systems, however, are not being considered as potential power sources for vehicles.

4. Nickel-Zinc

While the high level of present interest in this system is not directly related to electric vehicle development, the nickel-zinc battery has, potentially at least, performance parameters which merit consideration for vehicle applications. The substitution of zinc for cadmium should give it approximately double the energy density of the nickel-cadmium system (i.e., about 30 w-hr/lb), and the power density should be comparably high. There is no problem of material availability with zinc, the costs of the battery should be appreciably less than those of nickel-cadmium batteries, although as a nickel-alkaline system it is still likely to be expensive compared with lead-acid.

The major difficulty with the nickel-zinc system is the classic problem of obtaining an adequate cycle life from any rechargeable battery containing a zinc anode. General Telephone and Electronics, which is one of the companies investigating nickel-zinc cells, has reported cycle lives of 100-200 but at only 50% discharge, which nullifies its advantage over nickel-cadmium in energy density. General Electric has reported improved cycle life by incorporating calcium hydroxide in the electrolyte to limit the concentration of soluble zincate, but this too lowers the energy density. Also active in the field are Texas Instruments, Eagle Picher, Yardney Electric, and others.

Even if perfected, the nickel-zinc battery would still seem to be too costly as the prime power source for an electric vehicle, but it might have some promise in hybrid mechanical-electrical systems (see Section VI). Until a reasonable lifetime has been demonstrated, however, its prospects as a vehicle power source remain speculative.

C. FUEL CELLS

Fuel cells are essentially steady-state primary batteries and are of interest for electric vehicle applications mainly because vehicles so powered would have no requirement for electrical recharging. They would thus be no more restricted in range than are conventionally powered vehicles. Because of this, energy density is not a meaningful parameter for fuel cells, an evaluation of their applicability to vehicles turns upon their power density, reliability, and potential cost.

Fuel cells, which exist in a wide variety of types, can be differentiated by the nature of the fuel used – hydrogen, water-soluble substances such as hydrazine, methanol and ammonia, hydrocarbons – and by their temperature of operation: ambient, moderately elevated (80-150°C), or high (500-1000°C). Since hydrogen reacts so easily in a fuel cell but is an inconvenient fuel to handle, several types of fuel cells convert other fuels into hydrogen as the first step. These are called indirect fuel cells. The types of greatest interest for vehicle application are ambient-temperature hydrogen systems, both direct and indirect, and soluble fuel systems. On a conceptual basis the U.S. Army has also considered a high-temperature fuel cell-battery hybrid system involving a high-temperature hydrocarbon fuel cell.

1. Ambient-Temperature Hydrogen Systems

Ambient-temperature hydrogen fuel cells have reached a relatively high degree of reliability, and several thousand hours of trouble-free operation are now commonplace. The major limitations of these systems for application in electric vehicles are their relatively low power density and their high estimated production costs. As a general rule, restrictions on current densities imposed by problems of heat dissipation and electrode polarization limit power densities to levels of around 30 w/lb or so. More serious is the cost restriction, which has two major causes: 1) precious metal catalysts are necessary to generate acceptable current densities and 2) the problems controlling materials transfer across the boundaries of fuel cells make the engineering problems of the latter more complex than those of batteries.

The present state of the art in ambient-temperature hydrogen-air fuel cells is such that cells can be operated with no precious metal catalyst at all, but the current densities would be too low for vehicle applications. A loading of about 5 milligrams of platinum per square centimeter of electrode presently appears necessary to give a power density of 25 w/lb to a hydrogen-air fuel cell and this may be improved to 50 w/lb in ten years.[*] Present costs of such cells are no reliable index of future costs, since they are all essentially handmade. The most optimistic estimates for future volume production are in the range of

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[*] *The Automobile and Air Pollution: A Program for Progress.* Report to the Panel on Electrically Powered Vehicles (R. S. Morse, Chairman), U. S. Department of Commerce, October 1967.

$100-$150 per kw. To this must be added the cost of the fuel supply system. Cylinder hydrogen is probably impractical due to its bulk and weight, liquid hydrogen is a distinct possibility but will certainly add significant costs for cryogenic storage. Indirect fuel cells would require equipment to reform hydrocarbons or methanol or to crack ammonia. None of these possibilities appears likely to involve the addition of less than $50/kw to the first cost, and thus, $150-$200/kw seems to be a limiting cost range for such systems.

Operational costs are likely to be quite moderate if hydrocarbons or methanol are used as fuel, since the conversion efficiency of the fuel cell is much higher than that of the internal combustion engine. The extent to which there would be a road tax on fuel-cell-powered vehicles is a major unknown factor here. In addition, fuel cells with alkaline electrolytes would need occasional changes of electrolyte because of gradual contamination with atmospheric carbon dioxide.

2. Soluble Fuel Systems

Soluble fuel types will in general involve even higher first costs than will hydrogen fuel cells. Those using ammonia or methanol call for much higher loadings of platinum catalysts per unit area, and their power density is not as great. Relatively low costs would be associated with a hydrazine-fed fuel cell, but this material is presently too costly (hydrazine hydrate costs approximately $1.00/lb) and there seems little prospect for a great enough cost reduction to make it a practical fuel.

3. Direct Hydrocarbon Fuel Cells

Research activity continues with direct hydrocarbon fuel cells, using aqueous electrolytes, particularly phosphoric acid, at temperatures of about 150°C. While the reactivity of the hydrocarbons is higher than was earlier thought possible, the quantities of precious metal catalyst required are still, and are likely to remain, orders of magnitude higher than those which could be contemplated in an electric vehicle.

4. Platinum Availability

The use of platinum in fuel cells is potentially restricted not only by cost but also by availability. On the basis of today's technology, a full sized car powered by a fuel cell might have a platinum requirement in the range of 1 to 10 pounds. This should be compared with an annual world production of this element of about 60,000 pounds and an estimated reserve of 10 million pounds. Clearly, the world's present apparent resources of platinum are not sufficient to support the widespread use of fuel cells in vehicles. Considerable research effort is being expended in a search for alternative and noncritical catalyst materials, but the results to date are not particularly promising.

High-temperature fuel cells capable of utilizing hydrocarbons directly do not use precious metal catalysts and hold promise of a lower ultimate cost structure than those for other types of fuel cells. They are, unfortunately, excessively heavy, and the problems of reliability and control are exacerbated by the elevated temperatures.

5. Overload Capability

A consideration of the fuel cell's prospects solely in terms of cost per kilowatt may lead to an excessively pessimistic outlook, since some allowance should be made for its overload capabilities. Power rating is a term calling for close definition, if the demand for maximum power is infrequent, a much lower rating is possible for the fuel cell than would be possible with a battery power source. For example, Union Carbide's hydrogen-oxygen fuel cell for the GM Electrovan* had a rating of 32 kw but a maximum output of 160 kw. The exact degree and duration of overload possible with a given fuel cell system will vary with its individual peculiarities, but it seems reasonable to take a factor of three as being representative. In such a case the family car of Table 1 might be adequately powered by a 30-kw cell rather than one of 90 kw. Even so, at an estimated $200/kw, the fuel cell would be prohibitively costly.

6. Present Applications

While much effort is being expended in the United States and elsewhere on fuel cell development, relatively little is focused on highway vehicle applications, most probably for the reasons of cost. Major engineering programs at General Electric, Pratt & Whitney Division of United Aircraft, Allis Chalmers, Union Carbide, Texas Instruments, and Monsanto have been concerned more with the fuel cell's application as a power source for space satellites, both manned and unmanned, as a means of generating electricity from natural gas in the home (a program at Pratt & Whitney in which the Institute of Gas Technology also participates), as a power source for the military in the field, and as a power source for industrial vehicles, particularly fork lift trucks. Overseas, ASEA in Sweden has built fuel cells for submarine propulsion. (This and other European activities are reviewed in Appendix B.)

Direct application of the fuel cell to highway vehicle propulsion has been confined to two experimental vehicles: the GM Electrovan, powered by a Union Carbide hydrogen-oxygen cell, and an M-37 truck modified by the U.S. Army Engineers R&D Laboratory to use a Monsanto hydrazine-air cell. Some notes on these two vehicles are contained in Appendix A. In Europe the French Government is sponsoring an electric car program based upon a 25-kw hydrogen-oxygen fuel cell system (see Appendix B).

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* See Appendix A.

D. ELECTROCHEMICAL HYBRIDS

Many of the electrochemical power sources reviewed in this section have had certain favorable properties for the electric vehicle application, but some of their other properties might be unacceptable. The most common situation, exemplified by fuel cells and alkali metal-organic electrolyte batteries, is good energy density allied with inadequate power density. One solution to this difficulty is to use a combination or hybrid power source in which each component provides properties which complement those of the other. Thus, a low-energy-density, high-power-density battery such as nickel-cadmium can be combined with a high-energy, low-power battery or fuel cell.

There are a number of fairly apparent drawbacks to electrochemical hybrid systems. First, they are more complex than a single power source and thus require significantly more complicated control equipment. Second, the energy efficiency of the hybrid tends to be low because of the losses involved in the internal redistribution of charge among the components of the power source. A further difficulty is that, future high-temperature systems aside, the most suitable battery for the hybrid systems is nickel-cadmium which has the limitations of high cost and materials availability problems, previously noted. As mentioned elsewhere in Sections VI and VII, the development of high-power-density "pile-type" lead-acid batteries would improve the prospects of hybrid power sources.

In spite of these difficulties, electrochemical hybrid systems offer enough advantages to have been the subject of a number of detailed paper studies and the power source for at least one experimental vehicle. There are two subcategories: fuel cell-battery hybrids and battery-battery hybrids.

1. Fuel Cell-Battery Hybrids

Fuel cell-battery hybrids offer possibilities for improving the prospects of the fuel cell as a vehicle power source on two counts. The battery can be chosen to give the overall system an adequate power density and, since its specific costs are likely to be lower than those of the fuel cell, the overall cost per kilowatt will be lessened. The system retains the fuel cell's advantages of rapid refueling and a range limited only by the size of the fuel tank.

Union Carbide Corporation, which built the hydrogen-oxygen fuel cell for the GM Electrovan,* has carried out a conceptual study of coupling a fuel cell with nickel-cadmium batteries for the same application. It concluded that the same performance could be obtained by reducing the fuel cell stack weight from 1345 to 690 pounds and incorporating 427 pounds of nickel-cadmium batteries. Further weight savings would be effected in other parts of the system. The study was not intended to find the optimum makeup of the system but was merely a first approach based on the present state of the art. The battery would be capable of putting out 128 kw of power for short periods; based on a rule of thumb of $3/lb for nickel-cadmium battery costs, it would give peak power capability for about $10 per kw, considerably less than could ever be expected from a fuel cell.

Union Carbide has also constructed for demonstration purposes a small electric motorcycle powered by a hybrid combination of hydrazine-air fuel cell and nickel-cadmium batteries. The power rating of the fuel cell in the system was 0.8 kw.

Another approach to fuel cell-battery hybrid power sources is being studied at the U.S. Army Engineers R&D Laboratories at Fort Belvoir. This concept would combine a high-temperature hydrocarbon-air fuel cell of the type being developed at Texas Instruments, Inc., with a high-temperature alkali-metal battery (for which the SOHIO system is a likely candidate). The advantages include the ability to use conventional fuels directly, a high power density due to the properties of the battery, and the possibility of using waste heat from the fuel cell to maintain the temperature of the system, thus eliminating the need for a separate heater.

The high-temperature fuel cell-battery hybrid has certain logistic attractions for the military because it is designed to operate on standard hydrocarbon fuels, but it seems a rather remote possibility for general application. If the technical problems of their development can be solved adequately, high temperature batteries are likely to be the sole power source in a vehicle. The fuel cell would add increased range capabilities but at a higher first cost and much greater complexity.

2. Battery-Battery Hybrids

The most prominent example of the battery-battery hybrid is a system proposed by Gulton Industries, Inc., presumably to be the power source for the experimental vehicle being developed in Gulton's joint program with American Motors Corporation. It will consist of a high-energy-density lithium-nickel fluoride battery (see Section V-B-2) in combination with a high-power-density "bipolar" nickel-cadmium battery. The latter has a pile-type construction and has been developed by Gulton specifically for applications involving high discharge rates. The hybrid system is expected to combine the best features of both batteries.

The General Electric Company has used a hybrid battery system in its small experimental electric vehicle (see Appendix A). The major energy source is a lead-acid battery; to enhance the vehicle's acceleration, a small nickel-cadmium battery having about 5% of the capacity of the lead-acid battery is connected in parallel with it. The system apparently operates successfully, and the vehicle has significantly better performance than it would have with lead-acid batteries alone.

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* See Appendix A.

VI. MECHANICAL-ELECTRICAL HYBRIDS

The power source for an electric vehicle can, of course, be an electrical generator activated by some kind of combustion engine. Thus is the basic system used in diesel-electric locomotives and, to a limited extent, in large diesel-powered off-highway vehicles for heavy construction work. Combustion engines are inevitably a source of some pollution, but it is reasonable to expect that the pollution could be minimized if they were specially designed to operate at a constant power output, as would be possible in a hybrid system. The fluctuating power demand would be met by a battery connected in parallel with the generator. The system might take any one of the four forms shown in Figure 10.

Hybrid systems can, in principle, have any desired ratio of engine-generator to battery power. In practice, however, it would seem desirable to have the engine-generator capable of supplying the average power level used by the vehicle plus sufficient reserve to ensure that the battery never became fully discharged in normal driving situations. This would make the hybrid vehicle independent of battery charging facilities and would eliminate from consideration engines which are uneconomically small,* since the power/cost ratio of engines decreases significantly as the size falls to a few kilowatts.

An engine much larger than the average power rating is undesirable, however, since if it were being run at constant power, much energy would be wasted in overcharging the battery. Shutting off the engine when the battery is fully charged is not a solution to this difficulty, because the vehicle could not then respond rapidly to a demand for power greater than could be supplied by the battery alone.

The driving cycle used in the calculations of vehicle performance parameters (Table 2) indicates that the average power demand in the moving vehicle is about 24% of the peak demand. This may be somewhat on the low side for vehicle performance as a whole, since the cycle is concerned with city driving conditions. We have therefore arbitrarily chosen to consider the prospects for mechanical-electrical hybrids on the basis of the engine's having a continuous power output equal to 40% of the peak power demand. This would provide a good reserve for unusually prolonged operation at high power demand and also permit the use of power-consuming auxiliaries such as air conditioning.

Of the four possible systems shown in Figure 10 we consider the ac generator-dc motor combination (d) the most immediately promising. The ac generator is attractive because it has no brush maintenance and replacement problems, and because it can run at high speeds and is thus very compact. Moreover, the technology of mass producing such

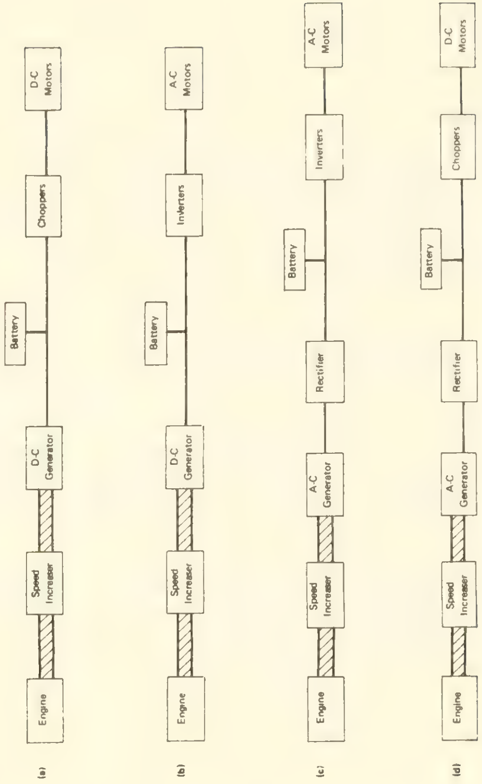

FIGURE 10 VARIOUS ELECTRICAL SYSTEMS FOR ELECTRICAL-MECHANICAL HYBRIDS

generators is well advanced because of the general introduction of the alternator in conventionally powered vehicles some five or six years ago. A dc motor is preferred however, for traction, as explained in Section IV the principal reason is the high cost and weight of the inverter system needed by an ac motor for speed control

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* The few hybrid vehicles in commercial production for use on the highway utilize a relatively small engine-generator system manufactured by G&M Power Plant Co. Ltd., of Ipswich, England. Designed for attachment to electric milk trucks and similar vehicles, the engine-generator serves merely to extend the range of what are essentially battery-powered vehicles.

To evaluate the technical requirements of the hybrid system we follow the same general procedure as that used for the purely electrochemical power source From the weight available for the power sources (line 17 of Table 1), we subtract the weight of an ac generator, rectifier, speed increaser, and voltage regulator rated at 40% of the final peak power requirement for each vehicle. The remaining weight can then be distributed between the prime mover and the battery Our approach has been to estimate weights for the former based upon existing technology and then calculate the power density which is required from the battery Provided it is sufficient to meet the demand for maximum power, the energy density of the battery is of secondary importance, since the source of energy is the fuel fed to the prime mover

Five different classes of engines could conceivably be employed in a mechanical-electrical hybrid system Three of these the gas piston engine, the diesel piston engine, and the gas turbine engine involve internal combustion, the others the Rankine cycle (steam) engine and the Stirling engine involve external combustion The latter two can be operated at lower overall pollution levels than the former, since external combustion can be carried out in a comparative excess of air (although oxide of nitrogen production is enhanced), nevertheless the data available on steam engines and Stirling engines in the size range of interest (reviewed in the recent report* by the Battelle Memorial Institute) are so meager that a separate analysis of their prospects in hybrids is not justified Since their power/weight ratio appears to fall within the same range as the diesel piston engine the calculations for this engine can be used as a first approximation for them

Representative data for the technical performance of gas piston engines and diesel piston engines in the size range of interest (6-60 kw) are plentiful and some data exist for the gas turbine at the upper end of this range Figure 11 shows some estimates of the weight-to-power ratio for these types of engines, and Figure 12 shows estimates of the corresponding factory costs per kilowatt These data are for engines with anticipated life times of 2500 operating hours, manufactured in quantities greater than a hundred thousand units annually and designed for constant power service at their rated load in a hybrid vehicle Their parameters therefore correspond more closely to the engine technology of long-haul truck service and industrial applications, where average operation is close to the rated power level, rather than to that of conventional automobile engines, whose average operation calls for only 20-25% of the maximum rated power For gasoline and diesel engines, which are very mature products, the power rating is the main influence on the power/weight ratio, and production volume is the main determinant of costs

The technology of gas turbines is well advanced, but the translation of this technology into economic solutions to the problem of automotive propulsion is in its infancy Few units exist in the size range of interest, and the estimated values in Figures 11 and 12 particularly of cost must be regarded as very approximate

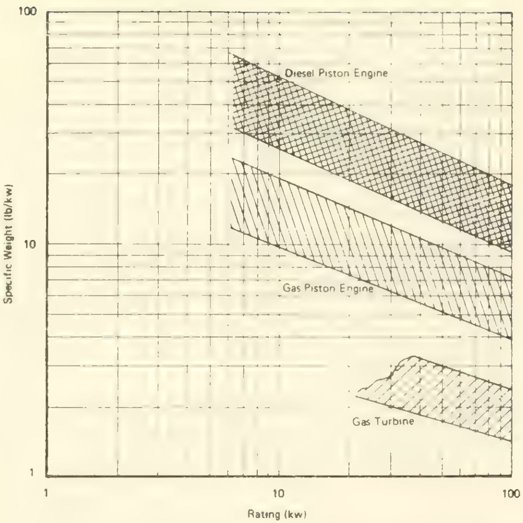

FIGURE 11 POWER/WEIGHT RATIOS FOR INTERNAL COMBUSTION ENGINES

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* Battelle Memorial Institute, "Study of Unconventional Thermal, Mechanical, and Nuclear Low-Pollution-Potential Power Sources for Urban Vehicles," by J. A Hoess, *et al*, Summary Report to U S. Dept of Health, Education and Welfare, March 15, 1968.

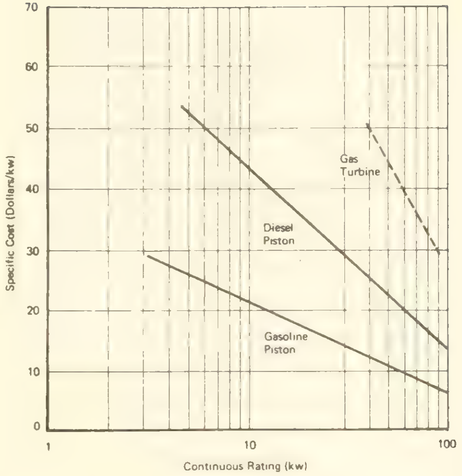

FIGURE 12 APPROXIMATE COST LEVELS FOR INTERNAL COMBUSTION ENGINES

The weight estimates for the ac generator are taken from Figure 13. These correspond to machines running at speeds of 12,000 rpm in the higher end of the power range and as high as 16,000 rpm in the lower end. They are representative of the technology used in equipment which is already in existence, particularly for aircraft applications, and which might be manufactured at low unit cost if sufficient demand developed. (Figure 13 also makes allowance for the relatively small extra weight associated with the rectifier and the speed which the system requires.)

Using the data from Figures 11 and 13, the weights of generator and engine rated at 40% of the peak power requirement have been calculated for each of the six classes of vehicle and for each of the three engine types. The permissible weight for the battery and thus its required power density are derived from these calculations and are presented in Table 5. The first two lines of the table are, respectively, lines 12 and 17 of Table 1.

The results of the calculations, which at first sight are somewhat surprising, indicate that the power density requirements for the batteries in hybrid vehicles are only slightly lower than for those in vehicles powered solely by batteries. These requirements are not particularly sensitive to the arbitrary choice of a 40/60 prime-mover-to-battery ratio. Thus among vehicles with gasoline engines and with conventional construction the family car shows essentially no change, while in the most favorable case, the city bus, the reduction is above 30%, from 36 w/lb to 25 w/lb. In the case of the diesel engine, the power density requirement for many hybrid vehicles is actually greater than when the battery is the sole power source; this results from the relatively high weight which must be assigned to the diesel engine.

Although the engines which would be used in the hybrid are smaller than those used in corresponding conventionally powered vehicles, the weight differences are not great. The larger maximum power capability of conventional vehicles does not call for substantially greater weight, because the engine is not built to run steadily at the higher power level. Also, the power density of internal combustion engines decreases as the size falls, so a small decrease in average power level does not return a proportional decrease in weight. The decrease in battery power density requirement for the hybrid involving a gas turbine engine is somewhat greater than for the two piston engines, but unfortunately the technology of small gas turbines is not well established, and their cost, which might be in the range of $40-$100 per kilowatt in the size range of interest, is likely to be discouragingly high.

The major differences between the battery requirements in the pure electric and the hybrid is that in the latter, 1) energy density is of small importance and 2) the maximum power density is reduced by about one-fifth. The power density requirements for the family car, however, still restrict the choice of batteries primarily to the high-temperature alkali metal type (among which the SOHIO system's high power density capability might be particularly attractive); the sole exception to this statement is the nickel-cadmium battery which has excellent power characteristics but low energy density.

For vehicles other than the family car, the power density requirements of the hybrid could be satisfied by metal-air battery systems; for various technical reasons, however (such as corrosion at the air cathode) this class of battery does not appear to be suitable for the

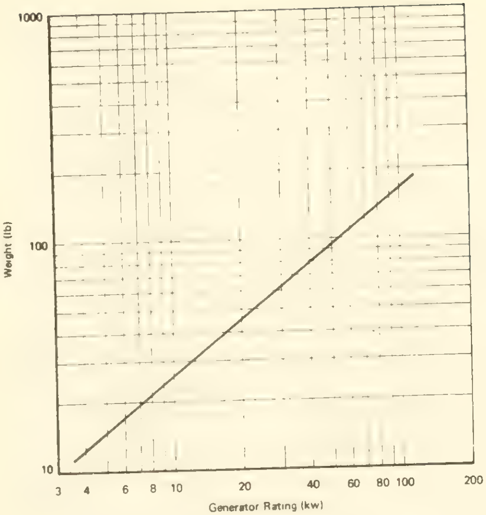

FIGURE 13 WEIGHT OF GENERATOR, RECTIFIER, SPEED INCREASER AND VOLTAGE REGULATOR

TABLE 5

HYBRID VEHICLE SPECIFICATIONS[a]

		Family Car	Commuter Car	Utility Car	Delivery Van	City Taxi	City Bus
Maximum output of hybrid power source	(kw)	85	29	17	62	47	159
Weight assignable to hybrid power source	(lb)						
Conventional construction		902	632	418	1,141	1,040	4,385
Lightweight construction		1,402	932	618	1,741	1,540	6,385
Weight assigned to generator, rectifier, speed increaser, and voltage regulator	(lb)	70	30	20	55	44	115
Weight assigned to engine	(lb)						
Gas piston		279	150	105	233	196	416
Diesel piston		715	395	295	600	512	1,010
Gas turbine		89	44[b]	32[b]	72	63	135
Weight available for battery Conventional construction	(lb)						
Gas piston		553	452	293	853	800	3,854
Diesel piston		117	207	103	486	484	3,260
Gas turbine		743	558[b]	366[b]	1,014	933	4,135
Weight available for battery Lightweight construction	(lb)						
Gas piston		1,053	752	493	1,453	1,300	5,854
Diesel piston		617	507	303	1,086	984	5,260
Gas turbine		1,243	858	566	1,614	1,433	6,135
Power density of battery Conventional construction	(w/lb)						
Gas piston		92	38	34	43	35	25
Diesel piston		440	82	97	76	58	29
Gas turbine		69	30	27	36	30	23
Power density of battery Lightweight construction	(w/lb)						
Gas piston		48	23	20	25	22	16
Diesel piston		83	34	33	34	28	18
Gas turbine		41	20	18	23	20	15

a) 40% of power supplied by prime mover, 60% supplied by battery

b) Power rating for commuter and utility car application considered to approach lower limits of feasible application of gas turbine "float charge" service characteristic of the hybrid application More important is the possibility that the lead-acid battery might qualify for the non-family-car hybrid applications The power requirements are somewhat high for it, except for the city bus, but its power density might be increased with further development of pile-type construction

From a cost standpoint, the prospects for the hybrid vehicle are generally unfavorable. In the smaller vehicles there would be virtually no saving in the cost of the prime mover to offset the extra cost of the generator, electric motors, control system, battery, cabling, etc. of the hybrid. The nickel-cadmium battery, whose present technical capabilities make the hybrid vehicle an immediately feasible proposition, is too expensive at $3/lb and could not be manufactured in the required quantities because of insufficient supplies of cadmium. Although they obviously face a prolonged period of development, high-temperature alkali metal batteries could eventually prove feasible for hybrids, however, their energy density would make them even more attractive as the sole power source of a purely electric vehicle, which is inherently a less complex and thus less costly solution

There appears to be one possible exception to these negative conclusions In the case of the city bus, the largest of the vehicle types considered, existing lead-acid batteries have a power density adequate for the hybrid. In the diesel-powered version, the cost of the battery might be about $3000-$4000, an acceptable figure in comparison with average total costs of about $30,000 for conventional full-sized city buses The slight reduction in the size of the engine would produce a small saving to offset the cost of motors and controls in this size range, but the economic attractiveness, if any, would probably come from lower fuel and maintenance costs, which are always important in commercial/industrial applications Enthusiasm for the hybrid city bus is, however, tempered by these facts 1) it is still basically an internal-combustion-powered vehicle and will contribute to air pollution, and 2) the number of buses is relatively small, so the elimination of their pollutants would make only a small contribution to solving the overall problem.

VII. PROSPECTS AND REQUIREMENTS FOR ELECTRIC VEHICLES

This section reviews the prospects for the six classes of electric vehicles, mainly in terms of the ability of the projected state of the art in electrochemical power sources to meet their technical requirements within an acceptable level of cost The future technology of motors and controls can be projected with somewhat greater confidence, although cost estimates are based on large extrapolations and are, at best, very approximate Some consideration is also given to the problems relating to the refueling of electric vehicles.

The findings of this study indicate the technical areas where most effort is necessary if the development of electric vehicles is to be accelerated. From these findings, and taking into account the anticipated progress of existing research and development programs in both the public and private sectors of the economy, a number of recommendations are made concerning the emphasis and direction of future effort

A. TECHNICAL PROSPECTS

The general technical capabilities of the various electrochemical power sources considered in Section V are summarized in Table 6 on the basis of values that might be attained when the systems now under development reach maturity While these generalized figures may not accurately apply to some individual systems, they will suffice for a first analysis of vehicle requirements

1. Family Car

	Conventional		Lightweight	
Requirements:	**Battery or Fuel Cell**	**Gas Piston Hybrid**	**Battery or Fuel Cell**	**Gas Piston Hybrid**
Energy Density (w-hr/lb)	135	–	87	
Power Density (w/lb)	94	92	60	48

The technical requirements for the power source of the family car are the most demanding of those for all six types of vehicles considered This is somewhat discouraging, since vehicles in this general category comprise approximately 80% of all vehicles on U S highways and are thus responsible for a correspondingly large proportion of the air pollution caused by vehicles It is apparent from the requirements shown in Table 1 that only the high temperature alkali metal batteries have any prospects of simultaneously satisfying the energy density and power density needs of this vehicle, regardless of the kind of construction While a number of the metal-air batteries might, with further development, meet the requirements for energy density in the family car with lightweight construction, they cannot meet the power density requirement. The same is true for fuel cells, and particularly so for organic electrolyte batteries

TABLE 6

GENERALIZED TECHNICAL PARAMETERS FOR ELECTROCHEMICAL POWER SOURCES

System	Maximum Energy Density (w-hr/lb)	Maximum Power Density (w/lb)
High temperature alkali metal batteries (rechargeable)	> 100	> 100
Metal-air batteries (rechargeable)	50-80	30-40
Alkali metal batteries with organic electrolytes (rechargeable)	75-100	15-20
Lead-acid	15-20	20-30
Special construction		60
Nickel-cadmium	15-20	75-100
Special construction		300
Fuel cells	–	30-40

As shown in Section VI, the power density requirements for a mechanical-electrical hybrid in a family car are not much lower than for the purely electrochemical power source They can, of course, be satisfied by high-temperature batteries and also by the nickel-cadmium battery, but the costs of the former are uncertain and those of the latter are known to be too high Pile-type lead-acid batteries, if their further development is successful, might also be marginally capable of meeting the hybrid power source requirements for the family car

Among electrochemical hybrid systems the power density of air-breathing fuel cells is likely to be too low to allow the hybrid to provide a sufficiently high power density, even in combination with high-power-density batteries The high energy density of the lithium-organic electrolyte battery in hybrid combination with a high rate nickel-cadmium battery could satisfy the technical requirement, this is unlikely to be a suitable power source, however, because of the particularly formidable technical problems associated with the development of rechargeable lithium-organic electrolyte batteries and the unavoidably high cost structure that this system would entail.

Thus, with the marginal exceptions noted above, it can be concluded that high-temperature alkali metal batteries are the only electrochemical power sources which appear technically suitable for use in the family car.

2 Commuter Car

	Conventional		Lightweight	
Requirements:	Battery or Fuel Cell	Gas Piston Hybrid	Battery or Fuel Cell	Gas Piston Hybrid
Energy Density (w-hr/lb)	41	–	28	
Power Density (w/lb)	46	38	31	23

Power source requirements for the commuter car are less stringent than for the family car Besides being a lighter vehicle and having lower acceleration capability, it has only one-half the range, as a consequence, the energy density requirement is about one-third, and the power density requirement is about one-half, those of the family car High-temperature alkali metal batteries should be able to meet these requirements with ease Metal-air batteries would have adequate energy density capability, but the maximum power density required in the commuter car with conventional construction is somewhat above the upper range of the expected capability of devices using air cathodes With lightweight construction, the power source requirements should fall easily into the range of capabilities of metal-air batteries and also of fuel cells

Among hybrid power sources, a high-power-density battery in combination with a fuel cell, lithium-organic electrolyte battery or an engine-generator would all qualify The power requirements are, however, too high for existing lead-acid batteries, and nickel-cadmium batteries are unacceptable on the grounds of cost and material availability

The commuter car thus appears also to require high-temperature alkali metal batteries, but rechargeable metal-air batteries would appear to have prospects of providing an adequate alternative

3. Utility Car

	Conventional		Lightweight	
Requirements:	**Battery or Fuel Cell**	**Gas Piston Hybrid**	**Battery or Fuel Cell**	**Gas Piston Hybrid**
Energy Density (w-hr/lb)	26		18	
Power Density (w/lb)	40	34	28	20

The requirements for the utility car are the most modest of the series Considering first the requirements for lightweight construction, the power source needs can be met by lead-acid batteries of the type representative of the best of today's technology and comfortably within what normal evolution should provide within a few years With conventional construction the utility car has a rather high power density requirement close to the upper range likely to be achieved by metal-air batteries. High-temperature alkali metal batteries, of course, easily satisfy all requirements of the utility car

While a number of hybrid power source systems, both mechanical-electrical and electrochemical, are technically feasible power sources for the utility car, their complexity makes them inappropriate for such a small vehicle

Thus, improved lead-acid batteries would seem to be technically adequate for this vehicle application, the higher performance metal-air batteries and high-temperature alkali metal batteries offer potential alternatives whose merit might be determined on the basis of cost

4 Delivery Van

	Conventional		Lightweight	
Requirements:	**Battery or Fuel Cell**	**Gas Piston Hybrid**	**Battery or Fuel Cell**	**Gas Piston Hybrid**
Energy Density (w-hr/lb)	50		33	
Power Density (w/lb)	55	43	36	25

The requirements for the delivery van with conventional construction show the need for a relatively high power density of 55 w/lb This is likely to be above the developed capabilities of the metal-air battery systems and of fuel cells As in the case of the family car it would appear that the delivery van will require high-temperature alkali metal batteries as its power source In a hybrid with a gas piston engine, the power density requirement for the battery falls to 43 w-hr/lb, but this is still attainable only by the high-temperature and nickel-cadmium batteries

With lightweight construction, however, the power source requirements for the van fall into a range likely to be attained by metal-air batteries, and in the gas piston hybrid vehicle the battery requirements might be accommodated by the lead-acid system.

While high-temperature alkali metal batteries seem in general to be the indicated power source for the delivery van, it is evident that a much wider range of possibilities would be opened up through the use of lightweight construction.

5. City Taxi

	Conventional		Lightweight	
Requirements:	**Battery or Fuel Cell**	**Gas Piston Hybrid**	**Battery or Fuel Cell**	**Gas Piston Hybrid**
Energy Density (w-hr/lb)	96		64	
Power Density (w/lb)	45	35	30	22

For the city taxi the energy density requirement is high, since it is equivalent to that of the family car but scaled down in proportion to its somewhat shorter range The lower acceleration performance demanded of the city taxi, however, reduces the power density requirement to less than one-half of that for the family car With conventional construction, this reduced power density still seems to be above the expected capability range for the rechargeable metal-air batteries, and high-temperature alkali metal battery systems again appear necessary In a hybrid vehicle with a gas piston engine, the nickel-cadmium battery would be satisfactory, and improved lead-acid batteries might also meet the power density requirements.

With lightweight construction, metal-air batteries should be capable of meeting the power source requirements for the city taxi, although the energy density specification might be close to the upper limit in some systems Lightweight construction would also appear to qualify the lead-acid system for inclusion as the battery in the gasoline-powered hybrid system

6. City Bus

Requirements:	Conventional Battery or Fuel Cell	Conventional Gas Piston Hybrid	Lightweight Battery or Fuel Cell	Lightweight Gas Piston Hybrid
Energy Density (w-hr/lb)	81	–	55	–
Power Density (w/lb)	36	25	25	15

The city bus with conventional construction has a high energy density requirement, a consequence of the frequent stops in its driving cycle and the value assumed for the range (which may be rather high for city driving service) The power density requirement of 36 w/lb is comparatively moderate. High-temperature alkali metal batteries are capable of meeting both energy density and power density requirements, and the latter is also within the range of metal-air batteries. A relaxation of the range specifications would thus allow the latter system to be an acceptable power source for the city bus With lightweight construction, the power source requirements should be well within the range of capabilities of metal-air batteries.

Hybrid systems offer some attractive possibilities for the city bus For both conventional and lightweight construction and for the three types of prime movers, power density requirements calculated for the battery are within the range of lead-acid systems The hybrid bus system thus appears to be feasible using components from existing technology which are likely to have an acceptable cost.

B. COST FACTORS

1. Considerations of First Cost

Cost estimates for the classes of electric vehicles under consideration in this study involve even greater uncertainties than in the evaluation of the technical factors. It is clear that no vehicle, electric or otherwise, has any prospect of becoming competitive until it is manufactured and marketed on a scale generally comparable with that of today's conventional vehicles. for passenger cars, the minimum level may be of the order of 100,000 units annually Even then, it seems very likely that the electric vehicle will have a significantly higher first cost As a broad approximation, fuel costs may be about the same for both electric and internal-combustion-powered vehicles when allowance is made for the heavy fuel tax on refined petroleum products.

A higher first cost may be acceptable for commercial vehicles, where the well recognized lower maintenance and longer life of electric vehicles will be a partial offset But for commercial and especially for private vehicles it will be necessary to regard the increased expenditure as a social cost attributable to the necessity of eliminating sources of air pollution. In these circumstances the desirability of electric vehicles must, of course, be evaluated in comparison with other potential solutions to this problem.

2. Family Car

Some broad perspectives on the costs of electric vehicles can be obtained by following the same general approach as for the technical factors, namely by taking an existing vehicle and considering which components should be replaced in the conversion from a conventional to an electric power source. If we take the family car as an example and assign to it a factory price of $1400, some $500 might be eliminated by removal of the engine, transmission, gearbox, and other ancillaries directly related to the use of an internal combustion power plant Replacement of these by electric motors, SCR controllers, speed reducers cabling, etc., according to the specifications shown in Table 4 would, on the most optimistic assumptions, add approximately $650 back to the cost. (This is based upon cost estimates per vehicle horsepower of $4 for a dc commutator motor, $2 for the controller system and $1 for cabling and miscellaneous; see Section IV)

Thus even before we consider the cost of the power source, the factory price of the electric vehicle would already be some 10% higher than that of a conventionally powered car The cost which can be tolerated for the power source is thus a rather subjective quantity, as there are clearly no savings to demonstrate In our opinion, an electric family car might be justifiable if its retail price were not more than approximately $1000 over that of a corresponding conventionally powered vehicle. Since average distribution costs should be unchanged, this would translate into a permissible increase of $1000 in the factory price.

Such a differential might be regarded as a premium for longer life and lower maintenance, but for private cars, some further incentive - probably in the form of selective taxation – would almost certainly be necessary While $1000 is a relatively large sum today, the period under consideration is in the 1980's at the earliest, due to the time required for technical development and cost reduction By then, personal affluence should have increased to an extent that such additional expenditure might be much less significant

If the allowable weight for the battery in an adequately powered family car with conventional construction is 900 pounds (Table 1) the allowable factory cost for the battery must be in the region of $0 95/lb With lightweight construction the allowable cost per unit weight of a battery just meeting specifications would be lower than this, for two reasons 1) it would be heavier (~1400 pounds), and 2) the use of lightweight nonferrous metals for structural members and plastic materials for body panels is likely to increase the manufacturing costs, leaving less money to be spent on the battery In this situation, to meet the cost criteria we have set, a figure of $0 50/lb is probably all that could be tolerated

These estimates are somewhat clouded by the question of battery replacement, since it is unlikely that the life of the battery will be as great as that of the rest of the vehicle Costs amortized over a five-year period are probably low enough to be written off against operating costs, but it must be recognized that a five-year lifetime introduces a significant new technical requirement for the battery

3 Commuter Car

For the commuter car the assumed factory price might be $800, with $200 assigned to engine, transmission, etc. Using the same basis for the costs of electric motors and controllers as for the family car, we find that the electrical components are comparably but slightly more expensive than the ones they replace ($210 vs $200). Thus, the cost of the power source can be equated with the extra retail price which we have assumed can be borne by the electric vehicle. If this is set at $500, the cost of the power source in the commuter car with conventional construction must be about $0.75/lb. Such a battery would have less than one-third the energy density and less than one-half the power density of the family car's power source. The performance of a battery capable of meeting the family car's requirements of 135 w-hr/lb and 94 w/lb would support a cost of about $1.90/lb in the commuter car, at $0.95/lb the first cost of the vehicle would be close to that of a conventionally powered vehicle.

4. Utility Car

Since no well-established model exists for a utility car constructed from conventional materials, the permissible cost of the necessary battery can only be estimated by judicious guesswork. Figures of $0.40-0.50/lb and a total cost of under $200 appear to be appropriate.

5. Commercial Vehicles

Somewhat less stringent cost requirements may hold in the commercial vehicle category, since for the van and bus, at least - production volumes are lower and unit costs relatively higher than is the case for passenger cars. Moreover, since the percentage of operating time is very much higher for commercial than for private vehicles and since the longer life and expected lower maintenance costs are better recognized, a higher cost structure for the battery can be tolerated. Inspection of the data for assignable weight indicates that $1.00-1.50/lb might be a reasonable estimate of the allowable cost for a power source which met the minimum technical requirements for the van, taxi, and bus with conventional construction.

6 Future Cost Structure of Power Sources

The above cost estimates for the vehicle power source, crude as they are, form some basis for an assessment of the prospects of the various power sources. As a point of comparison, it may be noted that today's lowest cost battery system, lead-acid, has an OEM price of approximately $0.25/lb in the high-volume application of automobile starter batteries. This is based upon relatively low-cost raw materials, the most expensive of which is lead at $0.13-0.16/lb, and a very mature manufacturing technology. For the lower production volume and longer-lived industrial lead-acid battery, OEM prices are in the range of $0.50-0.60/lb. Standard types of nickel-cadmium batteries, which are manufactured on a much smaller scale than lead-acid and use high cost materials (the raw materials costs being approximately $0.80/lb for nickel and $3/lb for cadmium), have a representative cost of about $3/lb in the 0.1 to 1.0 kw-hr size range.

Estimates of the potential cost structure of the new types of batteries now under development are very speculative. Among the high-temperature alkali metal batteries we believe that the capacitive storage device of SOHIO and the sodium-sulfur battery of Ford have prospects of achieving a cost level of approximately $1.50/lb in volume production, this seems to be a sufficiently encouraging basis for anticipating an ultimate price in the $1.00/lb range.

Metallic lithium, presently at $7/lb and with prospects of its price falling 50% as its production volume increases, might seem an expensive element for inclusion in a vehicle battery. However, its low equivalent weight results in a low requirement per battery, and with a lithium content of only 5-10%, the cost of this element should not be prohibitive. The GM lithium-chlorine battery seems likely to have a somewhat higher potential cost structure, less on account of the lithium than on the materials engineering problems associated with the handling of chlorine and the temperature (over 100°C higher than the other systems). The lithium-selenium and lithium-tellurium systems under investigation at the Argonne National Laboratory offer no prospect of developing into low-cost batteries because of the cost and the present scarcity of the cathode materials, selenium and tellurium. The recent work there on a high-temperature lithium-sulfur battery does, however, hold promise of yielding a low-cost battery.

Most of the rechargeable metal-air batteries now under development use acceptably low-cost materials (zinc, sodium, iron) as anodes. While air is free, a significant material cost is involved in the catalysts needed for effective and long-lived air cathodes and for the structural material of the cathode itself if it is to be used for oxygen evolution on recharge.

Electrically rechargeable metal-air batteries fall into two broad classes: those which involve some engineering artifice and those which have a relatively conventional construction. Among the former are the zinc-air batteries of General Atomic and Yardney Electric and the sodium-air battery of Atomics International. Both the zinc-air batteries are of some mechanical complexity, and the sodium-air battery may entail an appreciable materials cost for mercury. While there can be no firm estimates at this stage, the initial costs of these "engineering artifice" metal-air batteries in quantity production might be in the region of $3/lb with good prospects of falling to the $1.50-$2.00/lb region as experience with the systems grows.

Conventionally rechargeable zinc-air batteries, such as those being investigated by Leesona, ESB, Union Carbide, and McDonnell-Douglas, may cost close to $1.50/lb, since they would be of simpler construction. However, the fundamental technical problems associated with the recharging of the zinc electrode are so great that such batteries may never attain a cycle life acceptable for vehicle applications.

The characteristics of mechanically rechargeable metal-air batteries developed by Leesona in the zinc-air system, and considered conceptually by Atomics International for sodium-air, are not sufficiently established for conclusions to be drawn about their applicability to vehicles When their technology matures, first costs are likely to be comparable with those of other metal-air batteries, but operating costs will depend largely on the economics of reconstituting spent anodes, probably at centralized service stations, and at present these appear to be unfavorable This type of battery would be attractive, however, if it could be recharged electrically in regular service and mechanically recharged only during an occasional long trip.

The very approximate cost criteria which we have set for electric vehicles would appear to eliminate the prospects of the fuel cell, either as the sole power source or in a hybrid combination with batteries. A fuel cell is inherently a more complex and thus more costly device than a battery, because it has to accommodate the orderly passage of materials across its boundaries in addition to heat and electricity Moreover, there is as yet no indication that fuel cells whose performance is adequate for vehicular application will not require precious metal catalysts. Because of these limitations, ambient-temperature fuel cells seem unlikely to attain an ultimate cost structure of less than $2 to $3/lb. Although high-temperature fuel cells will probably have lower costs, their power densities appear to be too low. Any equipment required for pre-treatment of the fuel, such as reforming or thermal cracking, will add further to the first costs.

Some general comments on the costs of hybrid systems have already been made in Section VI If the hybrid is to be considered as a substitute for the conventional vehicle power plant, it is apparent that the cost of the engine, generator and battery must be compared with that of the battery or fuel cell of the purely electric vehicle. If we use the family car as an example and apply the cost criteria for the gasoline piston engine shown in Figure 12, the engine-generator costs for a 40-60, prime mover-battery hybrid would be about $500 (allowing about $2/kw for the ac generator rectifier and speed increaser). With $650 assigned to motors and controllers, offset by only $500 for the replaced engine transmission, gearbox, etc., the net extra cost is $650 plus that of the battery If the total cost is to be kept within $1000 of the cost of a conventionally powered family car, it is apparent that the cost of the necessary 51-kilowatt battery, weighing not more than 550 pounds, must be $350 or less Only the high-temperature alkali metal batteries and the nickel-cadmium system have prospects of this technical capability, and in this situation the latter is, of course, too expensive by a factor of at least five The cost criteria for the alkali metal battery used in a hybrid system are somewhat more demanding than when this battery is used in a purely electric vehicle, so that when such batteries become available there would seem to be no incentive for using them in hybrids.

As previously noted, the best prospects for the hybrid vehicle appear to lie with the commercial vehicles, and particularly the city bus The calculations of Section VI indicated that a 5000-pound battery with a power density of 29 w/lb (or less if lightweight construction is used) would be adequate in a diesel-powered hybrid It should be possible for a specially designed lead-acid battery to meet these criteria, using existing technology, for a cost of about $3000 Such a hybrid-powered bus would undoubtedly have higher first costs than a conventional bus, but the percentage increase should be substantially less than for the smaller vehicles.

To summarize, it seems apparent that electric vehicles are likely to have higher first costs than conventional vehicles, even in high-volume production and with maturation of the contributing technologies Some of this cost differential may be acceptable on the basis of lower operating costs due to a reduced maintenance requirement and longer life, but most must be attributed to the social benefits of decreased air pollution On the assumption that an additional $1000 might be placed on the retail price of the family car and perhaps an additional $500 for the commuter car, high-temperature alkali metal batteries appear to offer the best chances of meeting the cost criteria Metal-air batteries will probably have a somewhat higher cost structure and be acceptable only in commercial vehicles Fuel cells are likely to be too expensive, and mechanical-electrical hybrid systems appear promising only in the case of the city bus

C. REFUELING

It is apparent that the large-scale introduction of electric vehicles would have a major impact on a number of important sectors of the national economy This study, however, is concerned with the technology of the vehicle itself, the effects of the large increase in the use of power on the electrical generating industry,* the changes in the demand for materials, the impact on the petroleum industry, and the effect on the myriad of ancillary suppliers to the vehicle manufacturers are outside its scope Consideration is given to the question of vehicle refueling, however, since it has direct bearing on the selection of the vehicle power source.

Present-day conventional vehicles are refueled by the simple expedient of filling their tanks with gasoline or diesel oil as appropriate The whole operation can be carried out in five to ten minutes There would be no change in procedure for a mechanical-electrical hybrid, and an equivalent procedure is possible for a fuel-cell-powered system, although the nature of the fuel might set some special restrictions A vehicle powered entirely by batteries, however, clearly needs a totally different method of refueling This problem has been considered in terms of the three general options of rapid recharge, slow recharge, and mechanical replacement.

Rapid recharge would involve the acceptance of a full charge by the battery within a period of ten minutes or so, comparable to the time it takes to refuel a conventional vehicle A moment's consideration suggests that this mode of recharge is rather impractical. To recharge the battery in the family car in ten minutes would require a power source with a dc output of approximately one megawatt (allowing for inefficiencies) While we have not determined the probable capital costs of a dc rectifying system with this power capability, it is likely to be excessively high, even when manufactured on a large scale Moreover such a requirement for power would be likely to invoke a demand charge from the supplying utility The implications for the vehicle itself are even more severe Factors such as safety, insulation, and the cost of batteries are likely to hold the voltage of its electrical system to a maximum of 500 volts At this voltage, the wiring in the vehicle would need to carry a current of about 2000 amperes during recharge, which would require heavy and costly quantities of copper cabling A further consideration is the large and probably damaging amount of heat generated in the battery due to the inefficiencies of the charging processes

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*Complete conversion to electric vehicles today would create an additional load averaging about 40% of present electrical power consumption.

From the standpoint of battery technology, rapid recharging would be feasible only for systems having the highest power density. The ratio of maximum energy density to maximum power density, having the units of time, is a good index of a reasonable minimum recharging period for a battery. For this to be as low as ten minutes, the ratio must be less than 1:6, only the nickel-cadmium battery and possibly the SOHIO system seem likely to meet this criterion.

Slow recharge of a battery is considered to mean a charging period of from four to perhaps eight hours. The obvious time for this is at home overnight, or possibly at metered outlets when the vehicle is parked during the day. The rectifying equipment could be either on the vehicle or at the outlet. The advantages to this approach are the converse of the disadvantages of rapid recharge: slow recharging involves a very much lower investment cost in recharging equipment, the weight and cost of cables on the vehicle is less, the electrical efficiency is higher so that energy is conserved, there is less damage to the battery due to heating, and its lifetime is consequently lengthened. Home recharging also has the great advantage of making the motorist independent of visits to a service station, at least for refueling, and it would have the desirable effect of spreading the load on the electrical generating system largely onto the off-peak hours.

The obvious disadvantage of slow recharge is that the vehicle is unusable for a substantial part of the time. This probably would not be a serious difficulty, since the great majority of trips are undertaken for relatively short distances and on a fairly fixed daily schedule. Longer trips might depend on exchanging depleted batteries for fully charged ones at service stations, which raises questions of ownership and of battery standardization. Battery leasing with a metered use charge, might well be the procedure adopted. Maintenance work on batteries, such as occasional electrolyte replacement in alkaline systems, might be carried out during their residence time in the service stations.

For batteries with air cathodes an alternative to replacing the batteries on extended trips is the replacement of the anode alone. However, this procedure is certainly more complex and probably more costly.

It thus appears that the formidable technical difficulties associated with rapid recharging make slow recharging the necessary method of refueling, with mechanical substitution of batteries being used to extend the range on occasional long trips. This arrangement is less than ideal, but it appears to have enough advantages to make it acceptable.

D SUMMATION AND RECOMMENDATIONS

The general conclusion to be drawn from this analysis of the requirements for electric vehicles is that the necessary technology appears attainable, and that the cost of electric vehicles, while higher than that of conventional vehicles, might still be acceptable. A very substantial technical effort is called for if the required technologies are to be brought to maturity. One of the objectives of this study is to identify areas in which more effort might profitably be made.

For the electric vehicle to achieve performance broadly comparable to that of today's internal combustion powered cars, a low-cost, high-temperature alkali metal battery must be developed. The major virtues of this class of battery are their high energy density, which is a consequence of the high reactivity of the alkali metals, and their high power density, due to the rapid rate at which the electrochemical reactions take place at the elevated temperatures. Since the alkali metals are well above their melting point in these batteries, many technical problems of anode recharging are avoided. Of the alkali metals only lithium and sodium are serious candidates: lithium because it is the lightest, and sodium because it is the cheapest. Calcium, although having a high melting point (840°C), might provide an alternative anode material for high-temperature batteries; no work has been done in this area, however. Among cathode materials the most promising elements are sulfur and chlorine. It is also possible that phosphorus might be acceptable but its electrochemical properties are almost completely unexplored.

Bringing the technology of high-temperature alkali metal batteries to maturity will obviously be no easy task, since very formidable problems in materials selection and safety are evidently involved. Much engineering inventiveness will be required in the development of auxiliary heaters and insulation in the systems for temperature control, these complexities being appropriate only for batteries of the size capable of powering vehicles. The public acceptance of high temperature alkali-metal batteries is also a major question; the presence of a 900-pound battery containing alkali metals and elements such as chlorine or sulfur at a temperature possibly as high as 600°C is obviously not a particularly desirable feature for the family car. Effective, low cost insulating materials are clearly essential, and the design must make the battery as crash-proof as possible. Groups presently developing batteries in this class are optimistic that this can be done.

Given the requirement that the performance of a conventional vehicle must be matched, metal-air batteries appear to be too power-limited for application in the family car. They are likely to be somewhat more costly on both a weight and performance basis than the high-temperature systems, although neither technology is advanced enough to generate firm cost estimates. Metal-air batteries do, however, appear to have reasonable prospects for, the commercial vehicles, particularly if advances are made in the utilization of lighter structural materials. The metal-air batteries in general have a major advantage in that they operate at temperatures close to ambient. For these reasons further development of the metal-air systems seems fully justified. Moreover, there are prospects that the pattern of transportation, particularly in the cities, may change sufficiently in the future in the direction of smaller and less powerful vehicles so that the metal-air battery would provide a completely adequate power source.

Alkali metal batteries using organic electrolytes share the large advantage of operation at ambient temperatures and have high energy density, but their power density is low. The major problems limiting their future potential as a vehicle power source are the questions of whether they can ever be recharged at practical current densities and whether they can achieve an adequate cycle life. As in the metal-air batteries, it is conceivable that mechanical artifices might be introduced into these systems to overcome the electrochemical problems, but as yet such approaches have not been investigated. In view of its relatively less attractive prospects this class of battery does not appear to merit a major effort to adapt it for use as a vehicle power source However. it will undoubtedly see further development in view of its potential applications in other areas

Prospects for the fuel cell as a vehicular power source are rated as unfavorable partly because of its power density limitation but mainly because of its inherently greater complexity and cost relative to batteries. There thus seems to be no justification for a fuel cell development program oriented exclusively toward civilian highway vehicles, although fuel cells might well find vehicle applications in the military or specialized industrial fields

Our consideration of the technology of electric motors and controllers shows that vehicular requirements are certainly attainable and, in fact, can be largely met today. The major development effort for the future relates to the lowering of costs to a level acceptable for the vehicle application. The opening up of such a large market for these components would be a strong incentive for manufacturers to make such cost reductions. but it is evident that specifically oriented research programs will be needed to devise production techniques that will yield the extremely low unit costs demanded

Any formulation of recommendations for additional research and development programs in the technologies relating to electric vehicles must take into account existing and planned programs in these areas by other agencies, both public and private. A considerable budget is already allocated by the government for support of research and development on electrochemical power sources and the electrical technologies relating to motors and controls The two agencies most involved are the Department of Defense and NASA.

Within the Defense Department the greatest expenditures are by the Army Programs carried out and sponsored by the Engineering Research and Development Laboratory at Fort Belvoir, Virginia, have been concerned with novel electrical propulsion systems for military vehicles, with emphasis on gas turbine generators and fuel cells as the power sources. Support has been given to work on fuel cells using hydrocarbons (either directly in high-temperature systems or via a reforming or thermal cracking step), fuel cells using hydrazine. and various development programs concerning electric motor and control systems both ac and dc, which might be employed. The Army Tank Automotive Command at Warren, Michigan is also working on electrical systems development, complementing the work at Fort Belvoir. At the Electronics Command at Fort Monmouth, N.J., support has been given to work on fuel cells and on metal-air and lithium-organic electrolyte batteries. The latter is concerned mainly with primary batteries and is thus of little relevance to vehicles.

Work supported by the Navy has included programs on lithium-organic electrolyte primary batteries and on the identification of more effective and lower cost catalysts for ambient-temperature fuel cells The Navy is also concerned with the technology of advanced high speed electric motors, primarily for torpedo application.

The Air Force has supported most of the earlier work on rechargeable lithium-organic electrolyte batteries; it has also supported work on metal-oxygen batteries (which are closely related to the metal-air systems), and on fuel cells and rechargeable batteries for satellite applications. Much of the initial development of static inverter technology was carried out under Air Force sponsorship.

NASA's work in electrochemistry and electrochemical engineering includes the sponsorship of major fuel cell programs and related support for manned spacecraft power sources and the development of improved sealed, rechargeable batteries, particularly high rate nickel-cadmium and silver systems for satellite application NASA has also supported a good deal of work on lithium-organic electrolyte primary batteries, some on metal-oxygen systems, and has also been active in static inverter technology.

Total expenditures by all government agencies for research and development in the field of electrochemical power sources have been estimated at approximately $10 million annually, exclusive of the large fuel cell hardware projects relating to the Apollo manned spacecraft program. Expenditures of a further $5 million or so can probably be attributed to developments in the motors and controls field that have some bearing on the technology of electric vehicles. This latter figure includes estimates for that portion of the electric transmission systems developed for high-speed rail transportation which are applicable to self-propelled electric vehicles. The size of these amounts naturally varies with the definition of the relevance of the program and fluctuations in contract appropriations from year to year.

It is also important to recognize that most of the federally sponsored programs have been focused on such different objectives that they have only a very limited contribution to make to the development of commercially viable electric vehicles Thus, while NASA fuel cell programs have demonstrated that efficient and reliable fuel cells with electrical outputs of several kilowatts are feasible, the details of the technology are not translatable into the needs of a mass-produced, low-cost power source. Similarly, the work on vehicle systems being carried out by the Army naturally focuses on military field situations which involve specific requirements very different from those of the civil environment When the specific content of the programs are taken into account, it can be seen that only a small proportion of the federal expenditures are applicable to the problems of civilian electric vehicle development.

An account of private research effort in power source development has been given in the body of this report. An overall figure can only be a crude estimate, but it would appear that expenditures by U.S private industry on novel power source development relating to electric vehicles total $5-7 million annually. A substantial fraction of this is represented by the programs of the two major automobile manufacturers, and a proportion of the remainder is invested in anticipation of later support from federal agencies.

The magnitude of the technical problems involved in the development of batteries capable of meeting vehicle power source requirements and the increasing urgency of air pollution abatement in the cities both point to the need for an acceleration of technical effort if electric vehicles are to be an effective solution. If the assumptions about vehicle performance made in this study are correct, the major effort should clearly be directed toward extension of the scale of work on high-temperature alkali metal batteries The existing work in this area at GM, Ford, SOHIO, and Argonne National Laboratory is valid and valuable, but considering the magnitude of the technical problems and the massive implications of the development, a more comprehensive and coordinated program appears to be needed

Such a program might involve basic electrochemical studies of all elements that have prospects of satisfying both technical and cost criteria for the vehicle battery these should include lithium, sodium, and possibly calcium, magnesium, and aluminum as anodes and sulfur, chlorine, and possibly phosphorus as cathodes The prospects of air cathodes in high temperature systems should also be evaluated, and for completeness some attention should be given to the potentialities as cathodes of the halides and sulfides of the transition metals An important part of the program would be the characterization of the molten salt and ceramic systems which would be the electrolytes of these batteries Other work should focus on the materials selection and engineering problems of the battery Noncorrodable conductive materials for current collectors and suitable inorganic materials for separators and supporting structures, sealants, and insulating materials are all needed Materials selection and engineering design optimization are usually specific to a particular battery system, so that the initial work should be concentrated as far as possible on developments having the greatest general application. The technology of low-cost thermal control systems, heaters and insulation is another important area

The other major technical area deserving additional support is that of rechargeable metal-air batteries While their projected performance is not adequate for the most demanding of the vehicle applications, it may well be acceptable for the types of vehicles which may evolve from new patterns of transportation within the city The technical problems of directly rechargeable metal-air batteries will respond, if at all, to increased emphasis on the basic electrochemistry of the systems The engineering solutions such as those being worked on at General Atomic and Atomics International can, however, be supported at the development stage, since their difficulties are of a less fundamental nature Further work on the problem of developing low-cost catalysts for air cathodes is desirable and such work would also contribute to fuel cell technology

In the area of motors and controls the development of low-cost manufacturing techniques for components and systems should be encouraged, the technology is already in existence, but the chief emphasis has been on specialized, low-volume applications where cost is not important While the prospect of large commercial markets will certainly stimulate private research expenditures in this field, some judicious seeding of development funds could bring the technologies more sharply into focus for electric vehicle applications

In summary the technology of electric vehicles appears to be attainable quite possibly at an acceptable cost But this is unlikely to come about in less than ten to fifteen years and then only if substantial efforts are made at the present stage in the planning and execution of programs particularly in the field of power source development - which are specifically oriented toward the performance and cost parameters demanded by the vehicle application The technical risks of this endeavor are too great for the investment to be borne by private capital alone, particularly since the major objective is a technology desirable for its social good rather than for its profit potential.

APPENDIX A

NOTES ON ELECTRIC VEHICLE DEVELOPMENT IN THE UNITED STATES

While electric automobiles represented a significant proportion of all highway vehicles in the early 1900's, they had been almost completely displaced by the 1920's, due to improvements in the internal combustion engine Apart from some occasional attempts to market small specialized electric cars, the only continuing commercial activity in recent years, relating to highway vehicles, has been the manufacture of electric delivery trucks by the Battronic Truck Corp , a company jointly owned by the Boyertown Auto Body Works, ESB Inc and Smith's Delivery Vehicles Limited, a major British manufacturer Gould-National Batteries, Inc , manufactured a line of electric trucks in the mid-1950's, but discontinued the activity due to lack of demand Cushman Motors, Inc manufactured a dozen small, three-wheel vehicles powered by lead-acid batteries for the Post Office Department in 1959, and four larger vehicles were purchased in 1962 from a division of ESB, Inc At about the same time, National Union Electric Corporation converted some 50-60 Renault Dauphines to electric drive, the product being called the "Henney Kilowatt " Electric utility companies bought many of them, and several have been the subject of further conversions described below While not highway vehicles, electric golf carts are, of course a flourishing product, and personnel carriers for use at airports, resorts, and large industrial plants are becoming commonplace

Over the last few years there has been considerable activity in experimental electric vehicle development, mainly in anticipation of their much wider use in the future. This Appendix contains notes on some of these activities

A AMERICAN MOTORS CORPORATION – GULTON INDUSTRIES

AMC and Gulton have announced a joint program to develop a small electric car making use of a hybrid combination of Gulton's lithium-nickel fluoride batteries and high-power-density bipolar nickel-cadmium batteries (a concept described in Section V) The vehicle will seat three persons and weigh about 1100 pounds The power sources will be two 75-pound lithium batteries for energy storage and two 25-pound nickel-cadmium batteries to provide adequate power With regenerative braking, a 150-mile range is projected The limiting feature to this development would appear to be the state of the art in lithium batteries which have as yet not demonstrated a convincing degree of rechargeability in practical battery configurations nor an adequate shelf life

B ELECTRIC FUEL PROPULSION, INC.

This small company is manufacturing electric cars by conversion of the conventionally powered Renault-10 The power source is eight 12-volt, 205 amp-hour (5-hour rate) lead-acid batteries weighing approximately 1600 pounds. The batteries contain a cobalt additive which is claimed to reduce grid corrosion and thus give relatively longer life at high charging rates The car is heavy 4040 pounds curb weight compared with 1735 pounds for the original Renault-10 but the performance specifications are quite impressive 0-40 mph in 12 seconds, a maximum speed of 60 mph and a range of 70-120 miles under city driving conditions The car has a regenerative braking system. A substantial number (now approaching fifty) of these cars have been purchased or are on order by electric utilities and other companies interested in the electric propulsion field. Their evaluation should provide some valuable data on the operating costs of highway vehicles powered by lead-acid batteries.

C. ESB--BATTRONIC

As mentioned above, ESB, Inc , participates in the electric highway vehicle field via its part-ownership of Battronic Truck Corp The principal product of the latter company is a delivery truck having a loaded gross weight of 9500 pounds The load and battery weight combined are 5000 pounds and can be mutually adjusted to suit the route requirements within load limits of 2000 to 3000 pounds The batteries used are 84-volt lead-acid systems with capacities of either 425 or 340 amp-hours The range of the vehicles is about 40 miles with a top speed of 25 mph

ESB also operates a converted Renault Dauphine of the Henney Kilowatt type. This vehicle is powered by twelve 6-volt golf cart batteries rated at 140 amp-hours (5-hour rate), which give it a maximum speed of 40 mph, a range of 25 to 35 miles, and an acceleration of from 0 to 29 mph in 3 seconds

D. FORD MOTOR COMPANY

Published reports of Ford's activities with experimental vehicles are confined to its work with the "Comuta," a small vehicle built by English Ford, one of which has been shipped to Ford's Dearborn headquarters Comments on the Comuta are included in Appendix B

E GENERAL ELECTRIC

In October 1967, General Electric announced that it had built an experimental car having a maximum speed of 55 mph on level ground and a range of 40-50 miles under normal stop-and-go driving The vehicle, which had a magnesium frame and a fiberglass-polyester body, weighed 2300 pounds and could carry two adults and two children A novel feature was the use of lead-acid batteries as the main energy source with nickel-cadmium batteries in parallel to provide power for acceleration and hill climbing The combined weight of batteries in the hybrid power source was about 40% of the vehicle's curb weight.

F. GENERAL MOTORS

General Motors Corporation has constructed two full-size electric vehicles primarily for use as test beds–the Electrovair II, a converted Corvair powered by silver-zinc batteries, and the Electrovan, a converted GMC Handivan powered by a hydrogen-oxygen fuel cell. Both vehicles have substantially the same motor and control system, a novel, lightweight, high-speed (13,000 rpm) ac squirrel cage induction motor. This motor, which weighs 130 pounds and is capable of delivering a maximum of 1.3 horsepower per pound, receives power from a thyristor inverter. The present weight of the controls, however, tends to eliminate the weight advantage of the motor system used, the electrical system has a total weight of 550 pounds. The voltage of the system, 530 volts, is the highest used in any electrochemically powered vehicle.

Both vehicles were designed to have substantially the same performance as their conventionally powered counterparts. In the case of the Electrovair II, this meant an acceleration of 0 to 60 mph in 16 seconds and a top speed of 80 mph. The Electrovair's silver-zinc batteries, provided by Yardney Electric, weigh about 650 pounds and give a range of 40-80 miles under normal driving conditions. The hydrogen-oxygen fuel cell in the Electrovan was manufactured by Union Carbide and operates on cryogenically stored fuel and oxidant It has a continuous power rating of 32 kw A favorable characteristic of fuel cells is their capability of responding to temporary overload, the fuel cell in the Electrovan has an overload capability of up to 160 kw. Both vehicles are much heavier than their conventionally powered counterparts: 3400 pounds versus 2600 pounds for the Electrovair and 7100 pounds versus 3250 pounds for the Electrovan.

G. GOULD-NATIONAL BATTERIES, INC.

In cooperation with North Star Electric, a Minnesota electric utility, Gould-National has recently modified two Henney Kilowatt Renault Dauphines with improved battery and control systems. The original twelve 6-volt, 180 amp-hour golf cart batteries were replaced with eighteen 12-volt, 80 amp-hour automotive starter batteries of newly improved design, having a polypropylene case, internal connectors, glass mat separators, and improved plate construction These batteries give 20 watt-hours per pound at the 20-hour rate Using a GE solid-state control system, the modified Henney Kilowatts have a range of 65 miles compared with 35-40 miles for the original models under comparable conditions

H. ROWAN CONTROLLERS, INC.

The activities of this Westminster, Maryland, based company in the electric vehicle field are covered in the section on Italian activity in Appendix B

I U S ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES

As part of the U S Army's continuing development programs on various approaches to electrical propulsion in vehicles (see Section VII) USAERDL has converted an M-37 truck to fuel cell power The power source was a hydrazine-air fuel cell developed by Monsanto and constructed in 5-kw modules Four modules were used in the initial conversion to give a 20-kw rating, but the design allows for later use of an 8-module 40 kw fuel cell

The curb weight of the converted truck was 6000 pounds of which 700 pounds was taken up by a conventional dc series motor 525 pounds by the 20-kw fuel cell system and 300 pounds by the controller All of these weights are believed subject to further reduction The 20-kw power source permitted a maximum speed of 47 mph and steady climbing up a 20% grade When the 40 kw system is installed, accelerative performance will be fully comparable with trucks having the standard 94 hp gasoline engine

J WEST PENN POWER COMPANY

West Penn Power (a unit of Allegheny Power System Inc) is an electric utility headquartered at Greensburg Pa It has constructed a small open electric car for demonstration purposes The chassis and suspension were taken from a Volkswagen sedan, and an aluminum body was built onto it The power source is an assembly of six 12-volt 205 amp-hour lead-acid batteries, and the motor is a conventional 7 1-hp dc traction motor of the type used in the Henney Kilowatt The control system designed by West Penn uses thyristors The overall curb weight is 2160 pounds With this system a maximum speed of 50 mph has been attained, and under favorable driving conditions the range is as much as 50 miles

K WESTINGHOUSE

In 1967 Westinghouse announced the availability of the "Markette," an electric passenger vehicle for highway use, capable of carrying two passengers The vehicle was derived from the golf carts and personnel carriers which Westinghouse has manufactured since its acquisition in 1964 of Electric Marketeer of Redlands California It was intended as an auxiliary vehicle for special uses where its quietness, economy and smooth performance would offset its limited speed and acceleration With a curb weight of 1730 pounds the Markette carried 792 pounds of lead-acid batteries (twelve 6-volt 217 amp-hour) and its two 4 5-hp dc series motors provided a top speed of 25 mph in 12 seconds from a standing start The range at one stop per mile was about 30 miles The vehicle was designed from existing state of the art components and was priced at "under $2000 Optimal solid-state controls to give it greater operating economy would cost about another $500

The Markette has recently been temporarily withdrawn from production because it does not comply with all of the new federal safety requirements This points up a significant difficulty for developers of electric vehicles since changes in specifications can be very costly for vehicles made in small quantities

L YARDNEY ELECTRIC

The Yardney Electric Company is operating a Henney Kilowatt in which silver-zinc batteries have been substituted for lead-acid The higher energy density and power density of the silver batteries give much improved performance In the original conversion four batteries were used each having fourteen 85 amp-hour cells Their total weight was 240 pounds in contrast to the 700 pounds of lead acid batteries which they replaced Maximum speed was 55 mph acceleration 0-30 mph in 5 seconds and a steady-speed range of 80 miles Yardney is now planning to reconvert the vehicle for use with batteries of the same type but improved design (the original were intended for service in military aircraft), with which it hopes to improve performance still further

M ACTIVITIES OF INDIVIDUALS

Besides these activities of industry and government there are also instances of conversion of conventionally powered vehicles to electric drive by individuals Among these are the conversion of an MG roadster by Mr William Roden of San Diego California, and of a Karmann Ghia by Dr Hugo Myers of Los Angeles Mr John Hoke of Washington, D C has constructed his own electric car based on a conventional small car chassis All three of these vehicles are in regular use

APPENDIX B

NOTES ON FOREIGN ACTIVITY

While interest in electric vehicles is less widespread in Europe and Japan than in the United States, many countries, particularly the United Kingdom, are quite active in vehicle design, control development, and investigation of new types of electrochemical power sources. The motivation of this interest is generally concern about air pollution, although the use of small electric vehicles to relieve traffic congestion and parking problems in the cities is equally important. In Europe, petroleum-based fuels are taxed more heavily than in the United States, and, as a result, there is proportionately greater incentive to use electric vehicles. In the materials handling field, for example, well over half of European lift trucks are electric. Electric propulsion is thus at a higher level of acceptance than in the United States.

The following are some notes on the more prominent of the foreign activities.

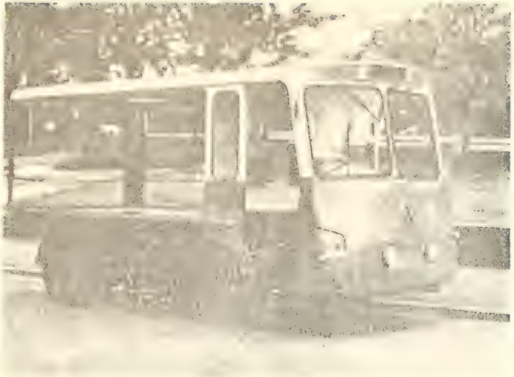
A. UNITED KINGDOM

Activity in electric highway vehicle development in the United Kingdom takes place at two levels. The first involves the manufacture of electric trucks for specialized purposes, primarily milk delivery, and is a well-established commercial undertaking The second concerns the development of a small car, generally a two seater for use as a commuter vehicle in urban areas. In addition, some research is being done on novel types of electrochemical power sources

The use of electric trucks on United Kingdom highways has increased substantially over the last 15 years, by the end of 1967 there were approximately 45,000 in service About 85% of them are for domestic milk delivery The most prominent manufacturers are Austin Crompton Parkinson (ACPEV), Smith's Delivery Vehicles, Stanley Engineering, and W & E Vehicles. A typical truck having a carrying capacity of about 3000 pounds is shown in Figure B-1 Power sources for these vehicles are typically 72-volt, 300 amp-hr lead-acid batteries, which give a range of 20-30 miles with 200 stops and a maximum speed of about 15 mph. Their robustness, ease of maintenance, and low-operating costs make them very popular with dairies and others engaged in door-to-door delivery.

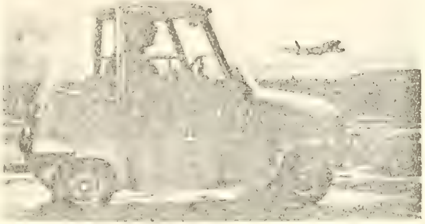
Hybrid electric trucks have recently appeared in the United Kingdom Some new models being offered by Austin Crompton Parkinson achieve extended range through use of a small propane-fed engine generator

Electric car development, which is still at the prototype stage, has focused on small vehicles, usually two seaters, to be powered by lead-acid batteries and to be priced at around $800. A photograph of the "Scamp", a typical vehicle of this type, is shown in Figure B-2 These vehicles generally have a maximum speed of about 40 mph and a range of 30-40 miles



Courtesy of W&E Vehicles

FIGURE B–1 BRITISH ELECTRICALLY DRIVEN MILK TRUCK



Courtesy of Scottish Aviation, Ltd

FIGURE B–2 THE SCAMP A DEVELOPMENTAL VEHICLE

under non-stop driving conditions. Table B-1 lists specifications for some of them. The two Electricity Council Minis and the Peel Trident are conversions from conventionally powered cars but the Scamp (of which a dozen were built) and the Ford Comuta were designed as electrics. All are two-seaters except the Trident, which is essentially a single-seater.

Besides the cars listed in Table B-1, design, mock-up, and prototype construction is being undertaken by Tube Investments, Hamblinetta (Flamenco), Carter Engineering (Carter Coaster) and Telearchics Ltd. (Winn City Car). These cars are being designed to have lightweight plastic bodies.

Most research on power sources has concentrated on fuel cells. Shell Oil Company carries out its research in England and has successfully demonstrated a 5-kw fuel cell system operating on reformed methanol with air as the oxidant. Chloride Electrical Storage, the largest British battery manufacturer, has shown a 2-kw hydrogen-oxygen cell fed by cylinder gas; it is used to power an in-plant tractor truck. Energy Conversion Ltd. is also active in fuel cell research.

In the battery field there is considerable interest in improved lead-acid batteries with thinner plates and higher energy and power density. This work is being carried out by battery companies such as Chloride and Oldham and at the laboratories of the Electricity Council. In the metal-air battery field, Joseph Lucas Ltd. and Crompton-Parkinson (Division of Hawker Siddeley) have cooperative programs with General Atomic and Leesona, respectively. British Motors has recently announced its interest in developing a vehicle to be powered by a zinc-air battery of the Leesona type in its subsidiary ACPEV, jointly owned with Crompton-Parkinson. No comment was, however, made on the prospective economic feasibility of such a vehicle.

Work on solid-state control systems is going on at Lansing Bagnall, Ltd. and at ACPEV. The initial application for this development is, of course, in the electric truck-materials handling area. Programs aimed at improving the characteristics of motors are being carried out at Bristol University and the laboratories of the Electricity Council at Capenhurst.

B FRANCE

The major French activity in electric vehicles is a government-coordinated program directed toward the development of a fuel-cell-powered car by 1971. Present plans call for the power source to be a hydrogen-oxygen fuel cell with a rated power of 25 kw.

Various aspects of this development program are being conducted by specialized contractors. The government-controlled automobile company, Renault, will build the vehicle, and companies such as CSF and C. F. Thomson-Houston are developing motors and control systems.

TABLE B-1

SPECIFICATIONS OF SOME BRITISH EXPERIMENTAL ELECTRIC VEHICLES

	Curb Weight (lb)	Motor hp (Continuous Rating)	Controls	Batteries	Acceleration	Maximum Speed (mph)	Range (miles)
Electricity Council AEI Mini-1	2,498	12 hp	Thyristor	96 v, 66 amp-hr (1-hr rate) 829 lb	0-30 in 12 seconds	41	30 non-stop at 37 mph
Electricity Council Telearchics Mini-2	2,378	2 at 3 hp	Carbon pile	64 v, 110 amp-hr (1-hr rate) 823 lb	0-20 in 5 seconds	40	28 non-stop at 40 mph
Peel Engineering Trident	600	24 volt 5 hp	Carbon pile	24 v, 153 amp-hr	0-30 in 7 seconds	35	
Scottish Aviation Scamp	1,000	2 at 2.7 hp	Carbon pile	48 v, 105 amp-hr (5-hr rate) 400 lb	0-30 in 10.5 seconds	35	30 non-stop
Ford Comuta	1,200	2 24 volt 5 hp	Thyristor	48 v, 85 amp-hr (1-hr rate)	0-30 in 14 seconds	> 30	40 at 25 mph

A major fuel cell program is under way at the Institut Française du Petrole supported by development work on carbon-based electrodes at Société le Carbone Lorraine and on sintered-metal-based electrodes at Ugine-Carbone. Other types of fuel cells are also under investigation: there are programs on a Bacon-type fuel cell at ONIA (Office National Industrial d'Azote) and on hydrazine fuel cells at Alsthom. This latter company has recently announced a joint vehicle development program with the automobile manufacturer, Peugeot. Metal-air batteries are under investigation at CIPEL.

An interesting example of electric vehicle application in France is the use of a battery-powered bus between the airport and the city of Marseilles. This is a full-size vehicle weighing 36,000 pounds and capable of carrying 26 people seated plus 54 standing. It is powered by a 96-volt, 750 amp-hour lead-acid battery that provides a range of 50 kilometers.

C. GERMANY

A small but significant number of electric delivery trucks were in use on German highways prior to 1950; the system of license fees was then changed so that the fees were based largely on weight, and this virtually eliminated the vehicles. In recent years there has been a revival of interest, although on a much smaller scale than in the United States and the United Kingdom. However, self-propelled rail cars powered by lead-acid batteries are in substantial use on the German national railroads. They were introduced after World War II, and about 300 are now in service.

Most of the work in Germany on novel power sources has been focused upon fuel cells. Both Siemens-Schuckertwerke and Varta have large groups working on hydrogen-oxygen fuel cell development, and Bosch has sponsored work on methanol fuel cells at the Battelle Institute in Frankfurt. The group at Varta has an interesting concept for regenerative braking. The energy from the generator is used to electrolyze water, providing hydrogen and oxygen which are stored and used subsequently in the fuel cell.

D. ITALY

Italian participation in electric car development is confined to the design and construction of small experimental vehicles with relatively conventional motor and control systems, powered by lead-acid batteries One of the more prominent of these vehicles, shown in Figure B-3, was built by Ghia S p A and De Tomaso Automobili, subsidiaries of the Rowan Controller Company of Westminster, Maryland This four/five seat vehicle has a curb weight of 1,300 pounds and is powered by lead-acid golf cart type batteries. The maximum speed is 40 mph and the range 50-100 miles, depending on driving conditions A relatively inexpensive solid-state controller is used which operates by switching the field current of the two 8-kw dc compound motors specially designed for this application by the General Electric Company The controller circuit is also utilized for regenerative braking

A very small electric vehicle called the "Urbanina" of unconventional design and for use in congested downtown locations has also been exhibited This car weighs only 800 pounds The passenger compartment holds two people and is in the form of a rotating turret A range of 50 miles and top speed of 38 mph have been reported Other Italian electric cars involve conversions of conventional Fiat 500's

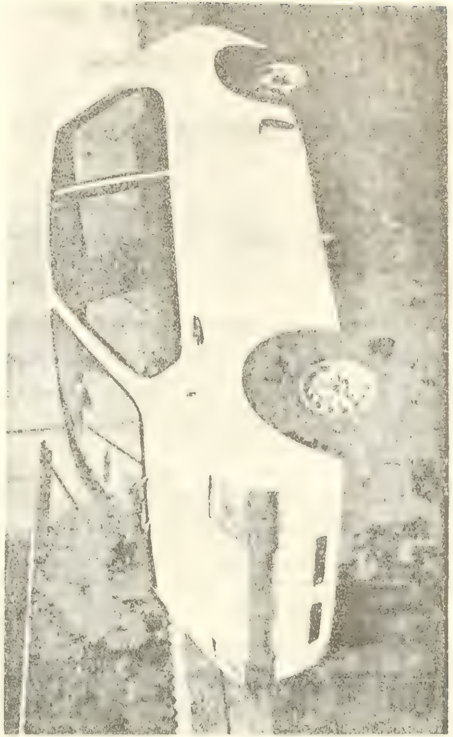
E SWEDEN

Urban concentration in Sweden is much less than in other developed countries, and the comparatively large distances between populated centers make electric vehicles less immediately attractive, nevertheless, interest in their development is strong The most notable Swedish activity is in fuel cell development ASEA has constructed the world's largest fuel cell system, which uses cracked ammonia and has a power rating of 240 kw The immediate application was as a power source for submarines, but smaller modules of the system have been used to power experimental lift trucks, and electric highway vehicles are also under consideration

In a recent demonstration co-sponsored by the local Stockholm electrical utility, ASEA exhibited an electrically powered SAAB This vehicle contained a 120-volt nickel-cadmium battery weighing 1 000 pounds It had a range of 25 miles, falling to about 15 miles in city traffic The top speed was 43 mph

F BELGIUM

The most significant work on electric vehicles in Belgium is being carried out by Ateliers de Constructions Electriques Charleroi (ACEC) which has developed a full sized diesel-electric bus This vehicle has twin electric motors built into its back wheels While built largely for experimental purposes the bus spends most of its time in local service in the town of Charleroi In the present model no auxiliary traction battery is used, electricity is supplied by the diesel-powered generators as needed



Courtesy of Rowan Controller Corporation

FIGURE B–3 PROTOTYPE ELECTRIC CAR BUILT IN ITALY
BY SUBSIDIARIES OF ROWAN CONTROLLER CORPORATION

G. JAPAN

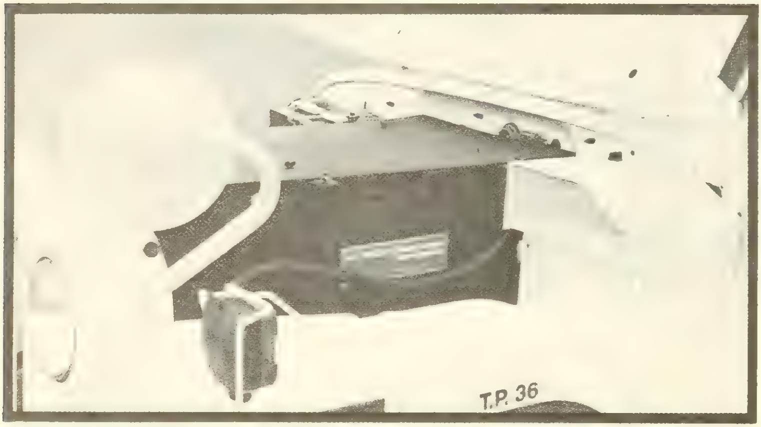
Japanese development of electric vehicles has been focused mainly on the conversion of small, conventionally powered cars to electric propulsion. The work has been prompted by the country's increasing concern about air pollution caused by heavy traffic in the cities. Three of these program are collaborative efforts involving a number of manufacturers and are organized by three utility companies Tokyo Electric, Kansai Electric, and Chubu Electric. The Kansai Electric and Tokyo Electric groups used standard lead-acid batteries in conversions of 800 cc and 360 cc vehicles, respectively, while Chubu Electric Battery Company developed a special 80-volt, 400 amp-hour lead-acid battery for its conversion of a 1,500-cc vehicle. All these vehicles are reported to have maximum speeds of the order of 40 mph and a range of about 50 miles at steady driving. All have thyristor controls and regenerative braking.

An interesting recent development is the announcement by Tokyo Shibaura Electric Company (Toshiba) of a small car powered by a high-speed brushless dc motor. Rated at 27 hp at 20,000 rpm, the motor gave the vehicle a maximum speed of 62 mph.

In addition to the above activity, the city of Osaka is reported to be contemplating purchase of a fleet of small electric buses for downtown use.

EV Power Sources

WAITING FOR A SUPERBATTERY



Single lead-acid battery will power Postal Service's forthcoming electrified vans. Developed specifically for the PS application by Gould Inc., Chicago, the semi-industrial, 54-v battery has 330-A-hr capacity (6-hr rate) and weighs 1,270 lb.

RICHARD A. JACOBSON
Senior Editor

THE WEAK LINK in EVs designed for street and highway use is the battery. Even if new electrochemistry systems are developed, EV batteries are not likely to be able to store enough energy to make possible vehicle performance and creature comforts matching those of the big, accessory-equipped, family cars of today.

Electric vehicles in everyday use, such as forklift trucks, golf carts, and delivery vans that travel short and fairly well defined routes, are energized by lead-acid batteries specifically designed for the application. Performance of these vehicles is adequate, but only because their jobs have been carefully hand-picked to be within the limited capabilities of the lead-acid system. Speeds do not have to be high, short range is acceptable, and recharging times either can be long, or spent batteries can be pulled out and fresh ones inserted.

No general-purpose electric car can become a reality until better batteries are available. Only the lead-acid type is ready now; development work on others is proceeding slowly.

Battery makers see two stages in the development of EV batteries. First will come power sources for a small car, maybe a two seater, that can function as the family's second vehicle. It will travel slowly and have limited range. Although it will be intended only for trips to the grocery store and the like, it will have greater energy reserves than present electric vehicles. The timetable for the mass-produced small car: perhaps in two or three years.

The second stage requires development of totally new batteries. These will provide adequate power for commuter cars having four seats—about the same size as compact cars of today.

Stamina and Muscle Needed

The most obvious shortcoming of the lead-acid battery is its "stamina"; it does not provide the range required for a general-purpose vehicle. Range is dependent upon the amount of energy stored in the battery (energy density in W-hr/lb). To get around problems of low energy density, electric-car builders load the vehicles with batteries; more than half of the vehicle curb weight may be batteries. Even so, range is short.

Lots of batteries under the hood also are needed to solve the "muscle" problem—the problem of power density, W/lb, which also is low for lead-acid. The power density determines how fast the car will accelerate and what top speed can be attained.

A case can be built for small, lightweight cars loaded with lead-acid batteries. At the Design Engineering Conference last April, Donald E. Semones, Battelle Memorial Institute, cited statistics that show a 20-mi travel range would suffice for 50% of the urban trips of all U. S. auto drivers, and a 40-mi range would cover 67% of all such trips.

A chart prepared by Semones shows that there is a lead-acid battery-powered vehicle today that can travel almost 100 miles and another that can attain speeds to 55 mph. However, the chart does not indicate what percentage of the curb weight is represented by the batteries and how much payload each vehicle can carry. For the "long range" and/or "fast" vehicle, Semones suggests that battery weight is excessive—there is room only for batteries, minimum hardware and frame, and a test driver.

Life and Other Problems

A test-bed electric vehicle that has seen considerable service uses 750 lb of lead-acid batteries, almost 46% of its curb weight. Twelve batteries are mounted in a tray that can be quickly removed for reloading.

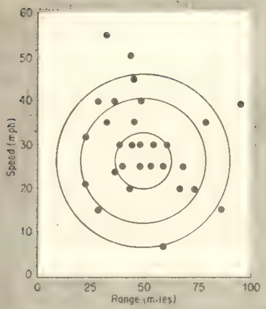
Suppose such a car were marketed and the batteries cost $50 each. If they were recharged every night and if they had a life of 1,000 cycles, $600 worth of batteries (minus trade-in price) would have to be replaced every three years. So both first cost of the batteries and cycle life are critical to the future of the electric car.

Battery life depends on a number of factors, including how deeply the batteries are discharged. Manufacturers of motive-power batteries talk about 300 to 2,000 charge-discharge cycles as being the

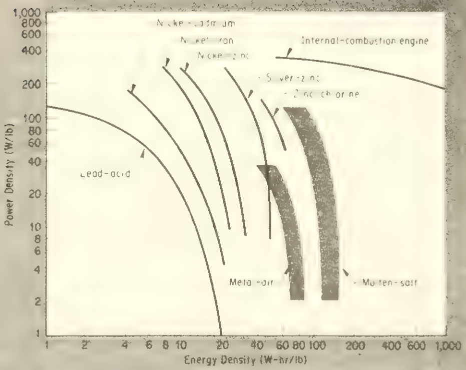
Recommended* Electric-Vehicle Specifications

	Family Car	Commuter Car	Utility Car	Delivery Van	City Taxi	City Bus
Maximum Velocity (mph)	100	80	65	55	75	55
Acceleration to (mph)	60	60	30	40	40	30
In (sec)	15	30	10	20	15	15
Range (miles)	200	100	50	60	150	120
Seats or Payload (lb)	6	4	2	2,500	6	10,000
Curb Weight (lb)	3,500	2,100	1,400	4,500	3,500	20,000
Stored Energy (kW-hr)	122	26	11	57	99	353
Conventional Construction						
Weight Assignable to Power Source (lb)	902	632	418	1,141	1,040	4,385
Power-Source Requirements:						
Energy Density (W-hr/lb)	135	41	26	50	96	81
Power Density (W/lb)	94	46	40	55	45	36
Lightweight Construction						
Weight Assignable to Power Source (lb)	1,402	932	618	1,741	1,540	6,385
Power-Source Requirements:						
Energy Density (W-hr/lb)	87	28	18	33	64	55
Power Density (W/lb)	60	31	28	36	30	25

*In "Prospects for Electric Vehicles," prepared by Arthur D. Little, Inc., and published by U. S. Dept. of Health, Education, & Welfare, National Air Pollution Control Administration [illegible] APTD 69-52



Speed and range for selected experimental electric vehicles. All are powered by lead-acid batteries; some have excessively high ratio of battery weight to curb weight. Bull's-eye technique for grouping the vehicles, advocated by Donald E. Semones, Battelle Memorial Institute, indicates that a range of 50 miles and a speed of 25 mph comprise the expected performance of electric vehicles today.



Power and energy capabilities of various batteries, and of the internal-combustion engine. Data for the familiar battery types are well established, although changing as improvements are made. Data for the advanced types are less trustworthy, representing the best educated guesses the battery industry can make at this time.

life range, and admit much research needs to be done in this area. One of the problems with the lead-acid battery is that high-energy density and long life in cyclic service are incompatible parameters. Another problem is that the less expensive lead-acid batteries generally have relatively short lives.

If quick recharge becomes a requirement for the electric vehicle, huge electric power sources and rectifiers will be needed, plus leads and batteries capable of accepting very high power inputs. The exorbitant power and equipment demands will require that careful study be given to the idea of a "filling station" where discharged batteries are exchanged for fully charged ones. An alternate is a filling station that houses a huge bank of batteries which would be float-charged continuously and then connected to quick charge the automobile. Instantaneous currents would be very high.

Another way around quick recharging is to use two trays of batteries. One tray could be charging while the other is in the car. This arrangement, of course, requires purchasing twice as many batteries.

In any case, the electric car will not be able to travel far from home until "filling stations" become common. If batteries are to be replaced at such stations, a reliable method must be developed to evaluate the condition of incoming and outgoing batteries. Unless this can be done, the station operator will have no logical method of establishing prices.

Projections from a Paper Study

A recent study by Arthur D. Little Inc. for the Federal government indicates that a 3,500-lb, six-passenger electric family car could be adequately powered by 902 lb of batteries able to produce an energy density of 135 W-hr/lb and a power density of 94 W/lb, as shown in the table. Even if the family car has special lightweight construction, thereby increasing allowable battery weight to 1,402 lb and keeping the curb weight of the vehicle the same, the battery figures drop only to 87 W-hr/lb and 60 W/lb.

But the best the lead-acid battery can do is produce energies of 16 to 20 W-hr/lb at low drains, and powers of about 35 W/lb for brief periods. Clearly, the lead-acid battery will not be a candidate power source for the full-size family car.

Other batteries now being developed also fall short of the ADL requirements for the 3,500-lb family car. But the lightweight family car may be feasible when these other batteries are ready for work.

Other types of personal road cars fare better in the ADL analysis, even though most cannot be powered by lead-acid. The tiny, two-seat, utility car (lightweight version) appears worth shooting for, if the lead-acid battery can be improved.

Battery makers and some vehicle builders do not agree with the energy and power densities of the ADL report. They say the figures are too high. Be that as it may, the study is, at this time, the most discussed guideline to battery development now available.

So the question remains, how much better than lead-acid types must the new batteries perform? Range of a commuter car powered by a 40 W-hr/lb battery system has been calculated and compared to the same vehicle powered by lead-acid batteries (12 W-hr/lb assumed). The calculations show that a modest increase in energy density allows a substantial performance improvement.

Batteries for Tomorrow

If the lead-acid system is not satisfactory, why not use some other rechargeable battery now available? Among these are nickel-cadmium—the most popular rechargeable cell for small appliances—and batteries that use silver-oxide as one electrode, especially silver-zinc.

Nickel-cadmium batteries in EVs would allow reasonable acceleration and speed; the power density is high. But energy densities aren't much different from lead-acid, and costs are high. Nickel-cadmium is ruled out, therefore, on the basis of insufficient range and excessive costs.

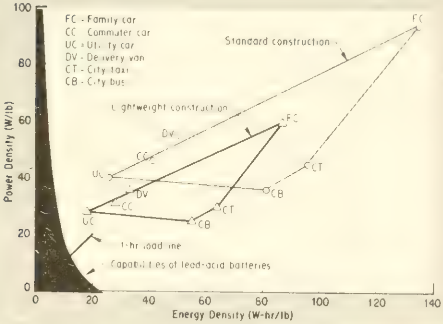
Silver-zinc has high energy density (50 W-hr/lb) and excellent power density (200 W/lb). Its problems are poor cycle life, plus very high cost which is partly due to the relative scarcity of silver. Silver-zinc batteries were used in one experimental vehicle, and the 500-lb battery pack was estimated to cost about $15,000.

And so it goes. The best overall battery available today is lead-acid, but it is not good enough. For tomorrow, however, a number of batteries are emerging from the laboratories. Each promises a practical lightweight utility car that meets the requirements of the ADL study, and some look good for a commuter car.

The cells nearly ready all use aqueous electrolytes and operate at or near ambient temperature. Among those often mentioned are nickel-iron and nickel-zinc. These two will perform a stopgap function, making feasible some limited-performance electric road cars, and will eventually be replaced by more powerful batteries, according to Dr. Edward E. David, Jr., executive vice president, research and development, Gould Inc. The two nickel-type batteries are very similar to lead-acid in construction, installation in the vehicle, and service requirements, he says. Projected manufacturing costs appear reasonable, because the nickel can be reclaimed.

The nickel-zinc system wins the nod over nickel-iron in all areas except cycle life. But David feels confident that the technology exists to solve the nickel-zinc cycle-life problem. Nickel-iron, David estimates, should be commercially available by 1976; nickel-zinc, by 1980.

The timetable could be all wrong, however. David expresses the problem of battery cycle life this way: "Some caution is necessary, for while it is relatively easy to create laboratory models of



Vehicles called for in the ADL report cannot be powered by lead-acid batteries. The one exception might be the lightweight utility car, and even this would require major improvement in the battery. To illustrate how big the improvement must be, the 1-hr load line crosses the lead-acid capabilities curve at the point (13, 13), meaning that if a car were driven for 1 hr at a speed requiring a power density of 13 W/lb, the battery would have delivered 13 W-hr/lb, and the vehicle would then be out of energy. This performance falls far short of performance required of the lightweight utility vehicle.

batteries incorporating unconventional couples, their reliability and cycle life are not so easy to assure.

"The failure mechanisms of batteries associated with usage cycling are not well enough understood to predict battery life reliably. Extensive and lengthy testing is thus necessary before any new battery can be brought confidently to market.

"This situation could be changed with adequate basic research, and that is one of the prime needs for the future. As of today, there has not been, so far as I know, testing of new batteries adequate to predict when reliable products will be available."

Another strong candidate to take over from lead-acid is the zinc-air system. Its big advantage is high energy density due to the fact that the cell does not have to carry all the ingredients needed to produce electricity—oxygen from the air reacts with the zinc.

Problems with zinc-air include low power density—although some experts predict this battery will eventually reach 45 W/lb—and short cycle life. As a primary (nonrechargeable) battery, the zinc-air system has found applications in many areas. But recharging zinc-air electrically has proved difficult. Mechanical recharging—replacing zinc electrodes and electrolyte—is possible, but is deemed unsatisfactory in the electric-vehicle application.

Much development work is being done in this area, and many battery experts feel an acceptable zinc-air battery is possible during this decade.

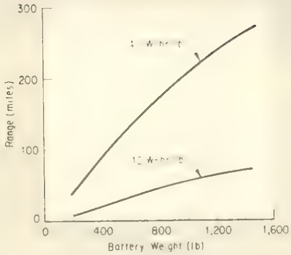
Molten Salt: Far Down the Road

One way to improve energy and power densities of rechargeable batteries is to use the lightest possible oxidizing and reducing materials. Another way is to use stronger reactants. Researchers are trying both of these approaches with a number of batteries that are now in early stages of development.

Among the best lightweight oxidizing agents are oxygen and air, the halogens, sulphur, and metallic compounds of these. The strong and light reducers include the alkali metals—especially lithium (the lightest) and sodium (the most plentiful and inexpensive).

The most suitable solvent for battery electrolytes is water—it's cheap, available, and relatively safe. But alkali metals react immediately when in contact with water, and therefore can't be used with aqueous electrolytes. Molten-salt electrolytes have been developed to accommodate the alkali metals.

The trouble is that molten-salt batteries contain highly reactive materials and operate at high temperatures. These facts promise safety and insulation problems for electric-car designers and, more immediately, create monstrous corrosion and sealing headaches for battery developers. Life of molten-salt batteries is short and must be improved.



Comparative vehicle performance is plotted by calculating the range for a commuter car (500-lb payload, 40-mph constant speed) powered by 40 W-hr/lb batteries and measuring the range of the car (same conditions) powered by lead-acid batteries (12 W-hr/lb assumed).

A molten-salt electrolyte must melt before the battery can operate. If the salt melts at 500 F, there is no way to get the battery's operating temperature below 500 F. If 400-F operation is a goal, all that can be done is to look for a new electrolyte.

Many laboratories are developing molten-salt batteries of various types. Lithium-sulfur, lithium-chlorine, and sodium-sulfur systems are the ones most discussed.

Lithium-sulfur: The lithium-sulfur battery uses lithium chloride fused with other salts as the electrolyte. Operating temperature is about 750 F, and there are many problems with materials, plus short cell life.

Researchers at Argonne National Laboratory claim that the problems can all be solved, and they have set a goal of installing acceptable batteries of this type in a test car by 1980.

Projections based on tests of a new cell having an iron-sulfide electrode indicate that a medium-size compact car powered by a 600-lb battery of this type could achieve adequate acceleration and a range of 100 to 150 miles. According to Argonne experts, approximately 4,000 lb of conventional lead-acid batteries would be needed to match this projected performance.

Energy densities expected from lithium-sulfur sulfide batteries are greater than 100 W-hr/lb; power densities are considerably more than 100 W lb.

Lithium-chlorine: Early this summer, researchers at General Motors announced that they had reduced the operating temperature of a lithium-chlorine cell to 800 F. This was done by going to an unconventional electrolyte—a molten mixture of lithium fluoride, lithium chloride, and potassium chloride.

Performance of the laboratory cell has led to cautious optimism; energy density is 150 W-hr/lb and power density reached 280 W/lb. These results, when adjusted to reflect the projected weight of other components that would be required in a vehicle-battery system, indicate 100 W-hr/lb and 100 W/lb might be feasible. However, a significant increase in cell life, currently 668 hr, must be achieved.

Progress has been impressive on this battery. One problem that has been solved—at least in the laboratory, if not on production models—is that of handling the gaseous chlorine that evolves during charge and feeds back into the cell on discharge. The chlorine is stored in activated charcoal within the high-temperature cell.

The standard electrolyte for lithium-chlorine cells is molten lithium chloride, requiring operation at 1,200 F. For this type of vehicle-battery system, energy densities are projected to be as high as 200 W-hr/lb, and power densities to 180 W/lb. But because of the 1,200-F temperature, corrosion and thermal expansion problems pose severe difficulties. Seals break down quickly, and the cells then begin to leak electrolyte.

There have been numerous attempts to ease material and sealing problems of the lithium-chlorine cell. Researchers at Standard Oil Co., for example, have designed a cell that uses fused lithium chloride/potassium chloride as the electrolyte, allowing operation between 662 and 932 F. Temperature buildup is somewhat of a problem, and the cell operates close to the upper end of the allowable range. Also, the cell voltage drops as reactants are used—that is, with discharge time—a disadvantage requiring sophisticated power-control equipment. Energy density of this cell is projected at 70 W-hr/lb; power density, 100 W/lb.

Battery experts agree that lithium-chlorine cells are very promising, but practical batteries of this type are not a commercial likelihood during this decade.

Sodium-sulfur: The sodium-sulfur battery is generally classified as a molten-salt type because it operates at high temperatures. Actually, it utilizes molten electrodes (sodium and sulfur) and a solid, ceramic electrolyte (beta-alumina) which allows passage of sodium ions from the liquid sodium side to the liquid sulfur.

Main backer of sodium-sulfur systems for EV power is Ford Motor Co. The company conservatively estimates that 100 W-hr/lb, 100 W/lb, and a life of 5 years (1,000 cycles) can be obtained. Cell-operating temperature is about 570 F, and won't come down because the electrodes must stay liquid.

Problem areas, again, are materials and seals. But when (and if) these problems are solved, the sodium-sulfur battery may have an advantage over other molten-salt types: both sodium and sulfur are abundant materials. Mass production of batteries won't deplete the reserves of sodium and sulfur.

Zinc-Chlorine: High Energy, Low Temperature

Perhaps the most promising long-term answer to the EV battery problem is the zinc-chlorine system. It operates at ambient temperature.

Zinc and chlorine have been regarded as an attractive combination for a long time, except for one problem: safe handling of deadly chlorine.

Chlorine in either a liquid or gaseous state requires heavy steel pressurized containers and is a corrosive and noxious material. It is not suitable in this form for battery operations. Nor will the solution for the lithium-chlorine, molten-salt battery work; temperatures are not high enough.

In the new battery, chlorine gas is chilled in water until it forms chlorine hydrate, a chemical that acts and looks like a yellow-green ice and can be held safely in bare hands. The concentration of chlorine in this safe form is still 40% by weight, allowing high energy and power densities.

The battery uses a closed system of water, chlorine, and zinc. During charging, chlorine is released from the battery into a storage tank, where it is immediately cooled to form chlorine hydrate. When the battery is discharged, the chlorine hydrate is warmed, and chlorine gas is returned in very low concentrations to the battery. There is, of course, a considerable amount of hardware that is needed in this system.

The feasibility of the zinc-chlorine system as a power source was demonstrated in 1972; experimental batteries weighing 1,680 lb were installed in a compact-size automobile and driven 150 miles at an average speed of 50 mph on a single charge. Curb weight of the vehicle was 4,289 lb; ratio of battery weight to curb weight, 0.39, which is very close to the ratio for the lightweight family car in the ADL study.

The zinc-chlorine (hydrate) system, predicts Philip C. Symons, Energy Development Associates, will have an energy density of about 70 W-hr/lb and a peak power density of about 70 W/lb. Dr. David anticipates that the battery will be less expensive than any other type considered for electric vehicles (even lead-acid) and it will be available before 1980. The only problem might be a relatively short life of 500 cycles, David believes.

EXHIBIT "A"

DEVELOPMENT OF ELECTRIC VEHICLES IN JAPAN

–Challenge for National Research & Development Program
by Introducing Most Advanced Engineering Innovations–

October, 1973

Agency of Industrial Science & Technology
Ministry of International Trade & Industry

DEVELOPMENT OF ELECTRIC VEHICLES IN JAPAN

I. National Research and Development Programs

Recently Japan needs greater and more positive efforts to develop new technologies in order to keep up the growth momentum of her economy and improve the welfare of her people—and that of all mankind—abreast the rolling tide of technological innovations sweeping across the world. In an effort to positively tackle the problems of developing new technologies, the Agency of Industrial Science and Technology of MITI instituted the System of National Research and Development Programs beginning from the fiscal year of 1966.

The System of National Research and Development Programs is directed toward promoting research and development of leading technologies of large scale, which are urgently needed for the development of Japan's economy, under the leadership and full sponsorship of the Japanese Government, with close cooperation from industrial and academic circles.

II. Background of the Development of Electric Vehicles and Development Programs

Noise and air pollution in big cities generated by the high density of motor vehicles have given rise to some serious social problems and every possible counter-measure has been taken for the solution of these crucial problems.

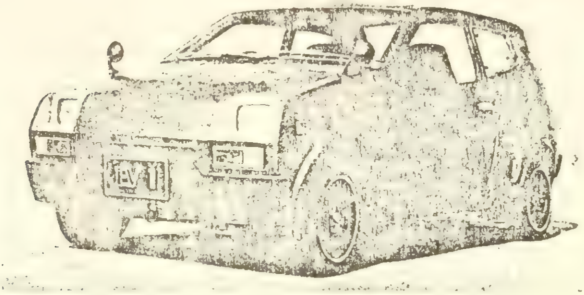
An electric vehicle, which has the intrinsic nature of emitting no exhaust gas and of generating less noise, should be considered as an ideal means of conveyance for the protection of environmental pollution caused by automobiles. In addition, this vehicle should be well qualified to play a key role in the new transportation systems due to the unique advantages in that, besides its simplified driving mechanism, automation of driving control can be feasible. However, it is a task of extreme difficulty to develop at an early date an electric vehicle whose performance can be well comparable with that of a gasoline-powered automobile. This is due to the reason that the great demand for development, on a nation-wide scale, of a high performance electric vehicle for city-bound transportation purposes has come to be emphasized.

In order to meet such demand, collective and systematical investigations on the development of electric vehicles have been conducted since the fiscal year of 1971 in accordance with the National Research and Development Programs, and also with a view to contributing to the control of automobile-base pollution and to the improvement of new city transportation system, joint research by the Government and all other organizations concerned on the basis of a five year program has been laid out with the allocation of approximately 14 million dollars. As a result, five types of experimental vehicles for the initial plan and such components as newly developed batteries and so on have been prepared by the fiscal year of 1973 as reported in the following:

III. Experimental Vehicles for the 1st Stage Plan

Lightweight Electric Passenger Car

Contractor: Daihatsu Kogyo Co., Ltd.



1. Structure & Features

- Adoption of ABS 3 layer plastic body and FRP floor pan.
- Adoption of rear 2 wheel drive (differential gearless) system containing 2 sets of DC motors and 2 speed automatic transmission
- Installation of a hydraulic and electric hybrid brake system having regenerative engine brake
- Installation of a high performance lead-acid battery adopting its replacement mechanism as a unit.

2. Specifications

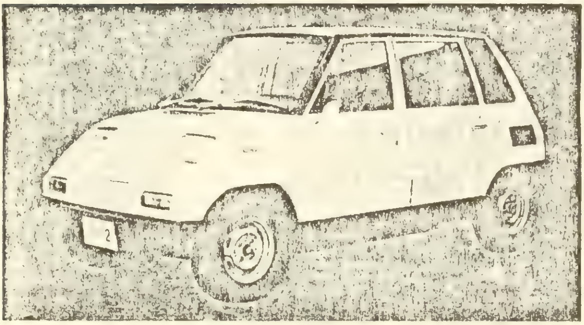
Dimensions	Overall length	3,165mm	Motor Control Device:		
	Overall width:	1,420mm		Type:	DC series motor
	Overall height:	1,315mm		Rated output:	2 x 5.6kW
Curb Weight:		912kg		Voltage:	2 x 45V
Gross Vehicle Weight:		1,132kg		Control system:	SCR chopper
Payload.		4 persons	Battery:		
				Type:	Lead-acid
				Capacity:	220 Ah/5HR
				Voltage:	96 V
				Number used:	4

3. Target Performance

Maximum speed	80km/h or more
Mileage per one charge (constant speed 40 km/h)	130 ~ 150km
Acceleration (0 → 30 km/h).	4 sec or less
Hill climbing ability (at a gradient of 6)	40 km/h or more

Compact Electric Passenger Car

Contractor: Toyota Motor Co., Ltd.



1. Structure & Features

- Body construction which assures comfort and handling stability as a passenger car.
- Light and stout upper body, constructed with steel frame and FRP panel.
- Power train with 3 speed automatic transmission capable to get high acceleration and speed performance.
- Hydraulic and electric hybrid brake system with high performance (regenerative brake).

2. Specifications

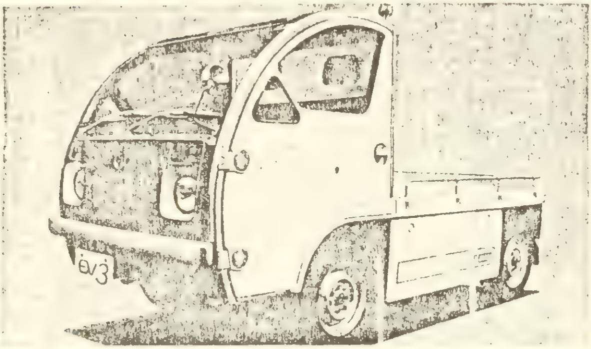
Dimensions:	Overall length:	3,350 mm	Motor Control Device:	
	Overall width:	1,580 mm	Type:	DC external exciting
	Overall height:	1,540 mm	Rated output:	20 kW
Curb Weight:		1,385 kg	Voltage:	192 V
Gross Vehicle Weight:		1,660 kg	Control system:	SCR chopper (automatic weak field)
Payload:		5 persons		
			Battery:	
			Type:	Lead-acid
			Capacity:	158.5 Ah/5HR
			Voltage:	192 V
			Number used:	16

3. Target Performance

Maximum speed:	80 km/h or more
Mileage per one charge (constant speed: 40km/h):	180 ~ 200 km
Acceleration (0 → 30 km/h):	3 sec or less
Hill climbing ability (at a gradient of 6°):	40 km/h or more

Lightweight Electric Truck

Contractor: Toyo Kogyo Co., Ltd.



1. Structure & Features

- Self-supporting frame of plastic sandwich construction, serving as a battery carrier.
- Safe and easy-to-operate drive train with the mechanism of locking and releasing motor shaft.
- Rubber suspension units designed to absorb vibrations.
- DC series motor effectively controlled by the voltage changing device and the SCR chopper controller.

2. Specifications

Dimensions	Overall length	2,915 mm
	Overall width	1,335 mm
	Overall height:	1,660 mm
Curb Weight:		780 kg
Gross Vehicle Weight		1,090 kg
Payload:		2 persons plus 200 kg

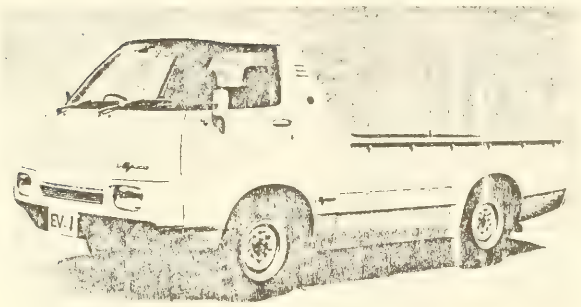
Motor Control Device	
Type	DC series motor
Rated output.	11 kW
Voltage:	90 V
Control system:	SCR chopper (change of voltage)
Battery:	
Type:	Lead-acid
Capacity:	200 Ah/5HR
Voltage:	96 V
Number used:	8

3. Target Performance

Maximum speed:	70 km/h or more
Mileage per one charge (constant speed 40 km/h).	130 ~ 150 km
Acceleration (0 → 30 km/h)	5 sec or less
Hill climbing ability (at a gradient of 6°).	40 km/h or more

Compact Electric Truck

Contractor: Nissan Motor Co., Ltd.



1. Structure & Features

- All FRP body with steel chassis frame securely retaining a traction battery.
- Rear motor, rear drive mechanism by geared motor.
- Hydraulic and electric hybrid brake system incorporating deceleration feed-back and load sensing control.
- Controller used for both speed control and charging without the necessity for external charger.
- High performance lead-acid battery adopting easy and quick battery changing mechanism.

2. Specifications

Dimensions:	Overall length:	4,695mm
	Overall width:	1,695mm
	Overall height:	1,830mm
Curb Weight:		2,440 kg
Gross Vehicle Weight:		3,550 kg
Payload.		2 persons plus 1,000 kg

Motor Control Device:		
	Type:	DC series motor, DC shunt motor
	Rated output:	27 kW
	Voltage:	120 V
	Control system:	SCR chopper
Battery:		
	Type:	Lead-acid
	Capacity:	460 Ah/5HR
	Voltage:	120 V
	Number used:	20

3. Target Performance

Maximum speed:	70 km/h or more
Mileage per one charge (constant speed: 40 km/h):	180 ~ 200 km
Acceleration (0 → 30 km/h):	5 sec or less
Hill climbing ability (at a gradient of 6°):	40 km/h or more

Electric Route Bus

Contractor: Mitsubishi Motors Corporation

1. Structure & Features

- Lightweight and strong monocoque body consisting of aluminum and plastic materials used in proper combination.
- Automatic variable field controller to adjust motor torque at the middle and high speed ranges.
- Standardization of lead-acid battery to enable speedy battery exchange in about 60 seconds.
- Hybrid brake system consisting of air servo oil brake and two-step regenerative brake.

2. Specifications

Dimensions: Overall length:	9,380 mm	Motor Control Device:	
Overall width:	2,440 mm	Type:	DC series motor
Overall height:	3,060 mm	Rated output:	75 kW
Curb Weight:	9,900 kg	Voltage:	375 V
Gross Vehicle Weight:	13,750 kg	Control system:	SCR chopper
Payload:	70 persons	Battery:	
		Type:	Lead-acid
		Capacity:	460 Ah/5 HR
		Voltage:	432 V
		Number used:	72

3. Target Performance

Maximum speed:	60 km/h or more
Mileage per one charge (constant speed: 40 km/h)	230 ~ 250 km
Acceleration (0 → 30 km/h)	8 sec or less
Hill climbing ability (at a gradient of 6°):	25 km/h or more

IV. Research and Development of New Type Batteries and Other Components

Main points are focused on the research and development of such components peculiar to electric vehicles as battery, electric motor and control system since they have a direct influence on the performance of these vehicles.

With a view to improving, to the maximum possible extent, density of energy and output energy of the battery whose performance has a potential influence upon the running mileage, maximum speed and accelerating ability of electric vehicles, prototypes of the following new models are in process of development.

(i) lead storage battery with multi-layer electrode (cathode)
(ii) lead storage battery with porous sheet-electrode
(iii) lead storage battery with thin multi-layer cell by the circulating system
(iv) zinc-air storage battery of the electrolyte fixed type
(v) zinc-air storage battery of the electrolyte circulating system
(vi) iron-air storage battery
(vii) sodium sulfur storage battery

In order to develop compact and highly efficient motor and control systems by making use of electronics whose development has recently been far advanced, prototypes of the following apparatus are now in the course of preparation.

(i) DC Motor and Thyristor Control System
(ii) Thyristor Motor and Power Transistor Control System
(iii) Induction Motor and Inverter Control System

Research is being conducted for the development of lightweight plastic body materials having chemical resistance for the purpose of replacing conventional ones.

With a view to facilitating the use and popularization of electric vehicles, research is now being conducted on the systems of utilization and recharging method.

Research on the establishment of procedures for testing and evaluation method of experimental vehicles and batteries has now been conducted.

V. Development of Final Experimental Vehicles

As stated above, researches on the initially planned experimental electric vehicles and new types of the components to be incorporated in these vehicles have been conducted by the fiscal year of 1973.

As for the future plan, it is contemplated that with further efforts towards the betterment of all the component parts by making the best use of their test results so far obtained, much more improved final experimental vehicles should be completed by the fiscal year of 1975 in order to let them serve as production models for one of the most ideal pollution-free transportation systems in the best interest of our urban life.

MAJOR FACTORS
ENCOURAGE THE USE OF ELECTRIC VEHICLES

by

A. H. Long
C. O. Peterson
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Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

Electrically powered road vehicles of one type or another have been around for almost 100 years. In the early 1900's keen competition existed between electric, steam, and gasoline powered cars. There was both competition on the road and a life and death struggle to become the preferred type. Although the gasoline car won a clear victory, in the mid-1960's a resurgent interest in battery powered road vehicles occurred. Experimental cars were built by corporations, schools, and individuals. Races were held, and intentions to go into production were announced. Despite this activity, an electric car business did not develop during the 1960's. Today, however, there are several factors influencing the possible widespread use of electric vehicles in the United States. In this paper we will assess recent factors that may influence development of electric vehicle business over the next decade.

The principal factors exerting a strong and challenging influence are:

1. Economics
2. Vehicle Performance
3. Conservation of Energy
4. Environmental Impact

Of these, economics offers the most compelling reason for the replacement of gasoline power by electric power. Indeed, in many cases, the influence of other factors will have its impact felt through the medium of economics.

ECONOMICS

Significant increases in the price of gasoline have been experienced in the United States and the rest of the world during the past year. The Arab oil embargo, balance of trade payments, and efforts towards a cleaner environment are factors that will continue the trend of increased gasoline costs. The outlook for petroleum as the sole energy base for future transportation needs is not encouraging, with drastic increases in gasoline prices predicted for the next decade. Responsible authorities and concerned users speak routinely in terms of $1-per-gallon-of-gasoline prices compared to 40 cents or less per gallon in 1973.

The impact of even the relatively ineffective emission controls by 1975-1976 standards on the gasoline consumption of 1973 and 1974 model cars has been alarming, compounding the effect of the gasoline price increases. It is not possible to predict with absolute certainty the effect of gasoline price increases and internal combustion engine emission controls on the total vehicle operating cost. The impact of these factors upon vehicle operating cost will depend to a considerable extent upon the service being performed by the vehicle.

An analysis has been made of a light delivery vehicle operating over a typical 24-mile multi-stop delivery route. Cost comparisons are made for a light delivery vehicle over the time period 1973 through 1983, comparing an internal combustion powered vehicle to that of an electric powered vehicle.

The total operating costs are separated into two categories: (a) "fixed costs" - those that relate to the ownership of the vehicle and (b) "variable costs" - those that are associated with the daily operation cost of the vehicle (see Table 1). The "fixed costs" include the initial vehicle cost, the annual insurance, and license. For the electric vehicle the cost for battery and charger are also included as part of the "fixed costs." The "variable cost" segment of the cost analysis includes the fuel, oil, maintenance, tires, and road use taxes. Other assumptions dealing with the expected life of the vehicles, the mission use of the vehicle, fuel economy, and fuel cost considerations over the period from 1973 to 1983 were:

1.0 Gasoline:

Costs - changing from $0.40 to $1.00 per gallon
Mileage - changing from 9 mpg to 6 mpg

2.0 Electricity:

Costs - 1.5¢ to 1.8¢ per KWH
Mileage - 0.500 KWH per mile

3.0 Emission Controls, Internal Combustion Engine:

10% First Cost Increase
100% Maintenance Cost Increase

4.0 First Costs and Life:

Internal Combustion Vehicle	$2500	(5 Years)
Electric Vehicle	$4000	(5 Years)
Battery	$360	(1 Year)
Charger	$550	(10 Years)

5.0 Mission:

24 miles per day
7500 miles per year

The result of this cost analysis and the expected influence upon total operating cost in cents per mile are illustrated as Figure 1. The predicted cost in cents per mile for both the electric and the internal combustion vehicles are approximately equivalent at 19 cents per mile in 1973. With a predicted gasoline cost of one dollar per gallon in 1983, the total operating cost (cents per mile) for internal combustion vehicles is shown to approximately double over the next decade to 35 cents per mile, twice that of the predicted operating costs for the electric delivery vehicle in 1983.

These considerations are far from being just academic. Organizations that operate large fleets of vehicles as part of their business are actively concerned about the trend of these economics. Their choices are clearly one of the following:

1. A disruptive change in established business patterns to avoid the use of vehicle delivery.

2. Find a lower cost alternative vehicle.

3. Raise prices, possible adversely effecting markets.

The electric vehicle appears to be a viable candidate for performing the function of the present internal combustion powered delivery vehicle in many cases and at a cost throughout the next decade permitting fleet operators to maintain the present mode of business patterns, and to do so at reasonable cost.

VEHICLE PERFORMANCE

At the Westinghouse Research and Development Center, two experimental electric vehicles, suitable for light delivery service, have been in operation since March of 1972 (Figures 2 and 3). These vehicles are fully licensed for road use and have accumulated nearly 7,000 miles of road testing in the Pittsburgh area.

The principal function of the vehicles has been to serve as a test bed for electric vehicle component evaluation. The battery compartment, accessed from the rear of the vehicle, is centrally housed between and forward of the rear wheels to accommodate a variety of battery packs and to facilitate quick replacement of the discharged battery. The engine compartment and front wheel drive enabled the use of a variety of drive systems. The vehicle characteristics are summarized as Table 2.

These electric vehicle test beds have been used for actual delivery and commuter mission testing. One mission consists of a simulated delivery route; others are actual postal delivery routes in the Pittsburgh suburban area. The postal route tests consist of following a U. S. Postal Service van through its daily run, matching the postal vehicle in all its stops and starts and performing the task at the normal in-route speed and pace set by the leading internal combustion vehicle. (see Figure 4)

The parameters of the simulated delivery mission are:

21.8 miles range
186 delivery stops-starts
74 traffic stops-starts
10.8 KWH per mission, energy drain from battery

The U. S. Postal Service missions are as follows:

	Route #35097	Route #12	Route #10
Miles Range	19.2	12.3	28.0
Stops-Starts	375	477	375
KWH Per Mission	11.0	8.75	15.1

In addition, a typical commuter mission with the following characteristics has been run:

33.4 miles range
33 stops-starts
13.3 KWH per mission

The commuter mission consisted of 14 miles of parkway-type driving and the remainder suburban street driving. The vehicle was able to maintain traffic speeds throughout the entire mission, matching accelerations and speeds set by the in-traffic internal combustion vehicles.

An instrumentation package specifically designed to obtain electric vehicle performance details includes an eight channel recorder, ampere-hour meter, kilowatt-hour transducer, motor tachometer, temperature pyrometer, and inclinometer. Typical data recorded on each of eight recorder channels during delivery-mission tests were:

Channel No.

1 - Motor current
2 - Motor voltage
3 - Battery terminal voltage
4 - Battery current
5 - Instantaneous battery power (KW)
6 - Motor tachometer (vehicle speed)
7 - Inclinometer
8 - Ampere-hours

By precise setting of the chart speed of the eight channel recorder, a plot of the measured parameter against time is obtained with the instrumentation package. Typical data derived includes vehicle range in miles, ampere-hours, the amount of mission time the vehicle is "in-motion" compared to "idle time," etc.

The curves of Figure 5 show the typical energy dissipation per mile for the electric vehicle. This data, obtained on a flat racetrack, illustrate the typical "U" shaped curve of watt-hours per mile versus vehicle speed. Energy consumption, watt-hours per mile, tends to increase with (1) decreasing vehicle speed due primarily to reduced motor efficiency at low RPM and (2) increasing vehicle speed, as a result of aerodynamic drag forces. As is evident, there exists an optimum vehicle speed with respect to energy dissipated per mile for each gear selected. For this vehicle, minimum energy dissipation is on the order of 200 WH per mile. Thus, for a 14 KWH battery the vehicle would be capable of 70 miles range at a constant speed of 30 miles per hour.

Verification of obtained test results and prediction of electric vehicle performance has been achieved through solution of the basic equation of motion at a given speed and acceleration.

Equation (1):

$$F = W\left(T_c + \frac{T_p}{p} + \propto \frac{V^2}{p}\right) + \frac{1}{2}\,\rho\beta A V^2 + W\left(S + \frac{A_{cc}}{g}\right) \qquad (1)$$

where:

F = Retarding force on the vehicle (lbs)
W = Gross vehicle weight (lbs)
p = Tire pressure (lbs)
T_c = Static tire resistance coefficient (lbs/lbs)
T_p = Tire pressure resistance coefficient (lbs)
$\propto$ = Dynamic tire resistance coefficient $[\text{lbs}/(\text{ft/sec})^2]$
V = Vehicle velocity (ft/sec)
ρ = Air density (lb/ft^3)
β = Aerodynamic drag coefficient (sec^2/ft)
A = Frontal area (ft^2)
S = Size of terrain grade (ft/ft)
A_{cc} = Vehicle acceleration (ft/sec^2)
g = Gravity constant (ft/sec^2)

has been computer programmed and represents the equation of motion for the electric test vehicle.

The first three terms take into account tire distortion, tread creep, hysteresis losses, and tire windage. Aerodynamic drag force is given by the next term. The last two terms are the forces necessary to overcome upgrades in the terrain and vehicle accelerations.

A calculated range of 70.1 miles at 30 mph is predicted by the computer solution of Equation (1). This compares well with actual test results of 71 miles.

The curve of Figure 6 shows instantaneous power dissipated as a function of time for vehicle acceleration from zero without gear changing. Peak power is limited to 29 KW by the current limit in the solid state controller. The sharp reduction in power from the peak value is characteristic of series wound dc motors. From the area under these curves instantaneous energy dissipated in accelerating the vehicle from zero speed in each of four gears without gear changing is available. This information is graphically shown in Figure 7. It can be seen that 120 watt-hours are expended in accelerating the vehicle from zero to 30 mph in second gear without a gear change.

These electric vehicle test beds have proven their usefulness in a variety of practical on-the-road missions in a repeatable and respectable manner. The experimental results, backed up by analytical analysis, offer convincing proof that electric vehicles are capable of performing many of the tasks presently being done by gasoline powered vehicles.

CONSERVATION OF ENERGY

Substitution of the use of energy in electrical form for the direct use of petroleum fuel for vehicle propulsion offers two important benefits.

First, the use of energy in electrical form offers a choice of prime energy source. Instead of being tied to petroleum fuel, electrical energy can be produced from a variety of sources, including coal, nuclear, hydro, geothermal, or even more exotic techniques such as harnessing tidal energy, or direct conversion of solar energy. This flexibility permits the selection of the optimum prime energy source or sources in any given circumstance.

The second benefit derives from the very low energy utilization efficiency of internal combustion powered vehicles, particularly in urban delivery and commuting service. A typical postal route studied requires three gallons of gasoline daily for the small vehicle now serving it. Taking the 12 KW hours of electrical energy actually required by test to perform the same mission (without regeneration) and taking into account all losses associated with electrical power generation, transmission and distribution as well as battery charge/discharge efficiency, it can be shown that only one-half that amount of petroleum fuel need be burned in a central station boiler to do the same job, considering the inefficiencies of petroleum transportation, refining, and distribution yields an even greater energy savings ratio (Figure 8). The actual fuel savings depends upon many variables, but it is very real and significant in any case.

Battery powered vehicles do not offer a total and immediate solution to the World's energy problems, but they are a step in the right direction. If the initial steps are taken now, advances in technology may well result in electric vehicles providing a significant part of the solution to the worldwide energy problems by the end of this century.

ENVIRONMENTAL IMPACT

The urban air pollution problem and the contribution of internal combustion engine powered vehicles to this problem have been subjects of much public concern for over a decade. Some possible implications were brought sharply into focus very recently, however, by the publication of the Environmental Protection Agency's estimates of the degree of restriction of internal combustion vehicle traffic that will be needed in various metropolitan centers to meet 1975 Air Quality Standards set forth in the Clean Air Act of 1970. The degree of restriction proposed varies greatly from one urban area to another; but it is certainly safe to say that, if such restrictions are found to be necessary, they will have a drastic effect on the urban and suburban American life style. Methods which have been discussed to implement restrictions include "dis-incentives" such as punitive licensing fees or taxes, or outright prohibitions of various kinds. Any of these methods provide the vehicle user with a strong incentive to consider the use of electric vehicles where they can perform the required tasks. Even though it can be argued that electric power generating stations are the sources of various forms of environmental pollutants, it is important to bear in mind that this pollution does not occur at the point of use, that is the congested urban areas.

CONCLUSION

There is ample evidence to suggest that electric road vehicles can be built using present day technology which would be capable of performance which is well suited to the many tasks for which gasoline powered vehicles are now used. It appears that there exist pressures which are strong now and which will become increasingly strong over the next decade for the substitution of electric for gasoline powered vehicles where this is possible. These pressures are felt in the areas of economics, critical fuel conservation, and environmental impact, all vital to our national as well as self-interest. With modest advances in battery technology, some of which are already in the pilot production stage, it is not unreasonable to imagine several millions of electric vehicles on the roads of the United States by the latter half of the 1980's and one hundred million electric vehicles by the year 2000.

TABLE 1

COST COMPARISON
(CENTS PER MILE)

	Internal Combustion Vehicle		Electric Vehicle	
	1973	1983	1973	1983
A. "Fixed Costs"				
Vehicle	5.3	5.8	8.2	8.2
Charger	–	–	0.7	0.7
Battery	–	–	4.3	4.3
Insurance	1.7	1.7	1.7	1.7
License	0.5	0.5	0.5	0.5
*	7.5	8.0	15.4	15.4
B. "Variable Costs"				
Fuel	3.1	14.6	1.3	1.6
Oil	0.1	0.4	–	–
Maintenance	6.5	9.0	0.7	0.7
Use Taxes	1.3	1.3	1.3	1.3
*	11.0	21.3	3.3	3.6
C. Total Costs (¢/Mile)	18.5	33.3	18.7	19.0

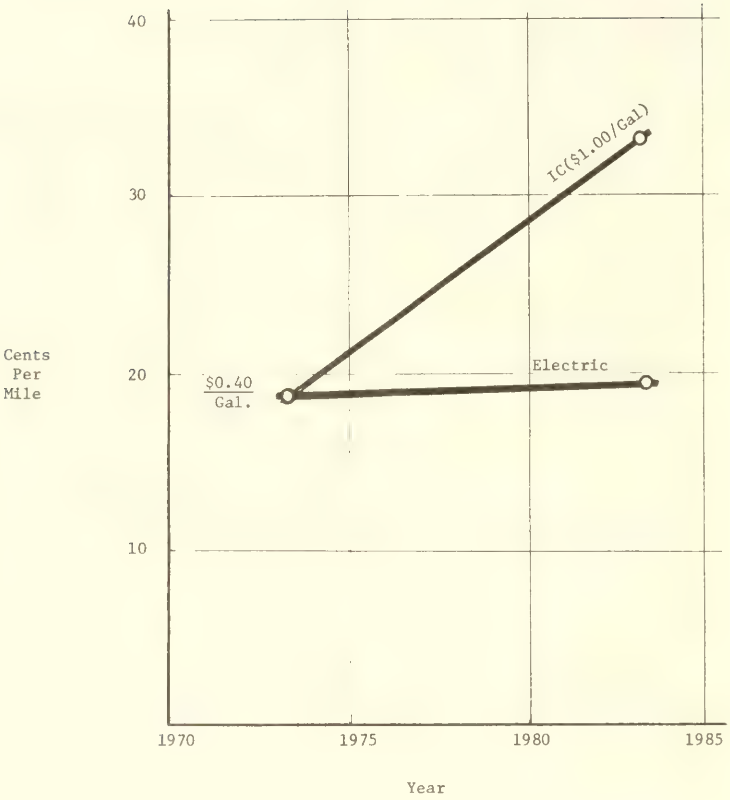
TABLE 2

VEHICLE CHARACTERISTICS

GROSS VEHICLE WEIGHT	3500#
Battery	1050#
Payload	500#
Driver & Passenger	350#
Vehicle	1600#
DRIVELINE	
Motor	96 VDC, Series Traction 24 HP @ 4000 RPM
Controller	Solid State Chopper - max current 400A
Transmission - 1	4 speed syncromesh
- 2	2 speed automatic
VEHICLE	
Wheelbase	85"
Total Length	142"
Front/Rear Track	48.5"
Width	63.0"
Ground Clearance	7.0"
Cargo Area	55 ft^3
Suspension	Coil springs and shock absorbers
Steering	Rack and pinion
Brake	Diagonal dual circuit, disc front, drum rear
Wheels/Tires	Radial 155 SR15
Body	Fiberglass reinforced polyester All-welded steel chassis
Doors	Sliding side doors, hinged rear door
Battery Compartment	Isolated from rest of vehicle, forced ventilation, access from rear of vehicle and floor of cargo area
ACCESSORIES	
Heater/Defroster	Liquid fuel
Auxiliary Battery	12V/60 AHR, charged by alternator
Fuel Gauge	Mastech, AHR meter with counter

FIGURE 1

TOTAL OPERATING COSTS



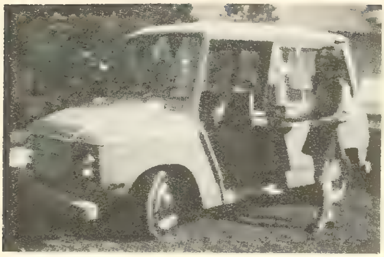


FIGURE 2
Experimental Electric Vehicle

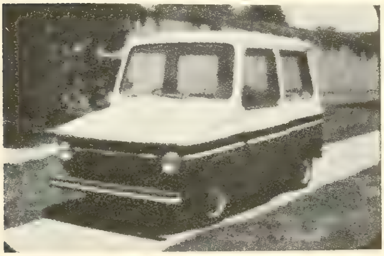


FIGURE 3
Experimental Electric Vehicle

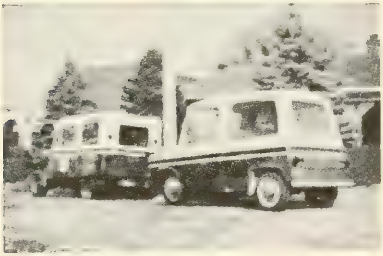


FIGURE 4
Electric Vehicle in U. S. Postal Mission

FIGURE 5

ENERGY CONSUMPTION PER MILE

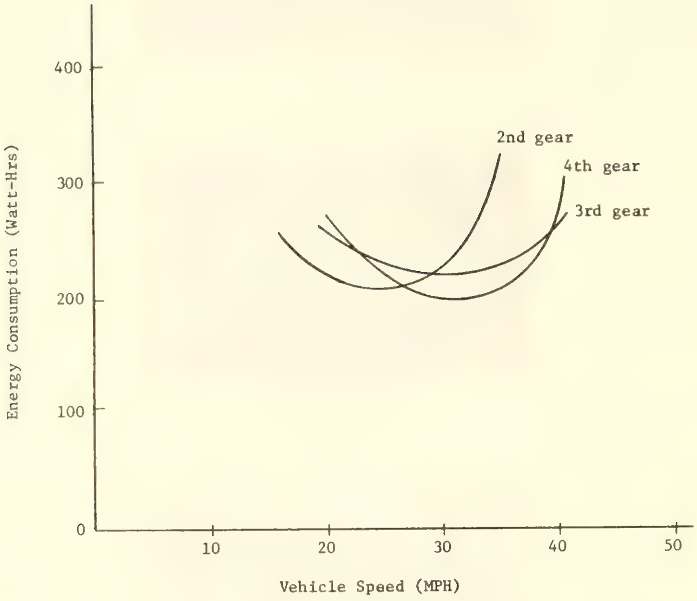


FIGURE 6

VEHICLE ACCELERATION
Instantaneous Power Vs Time

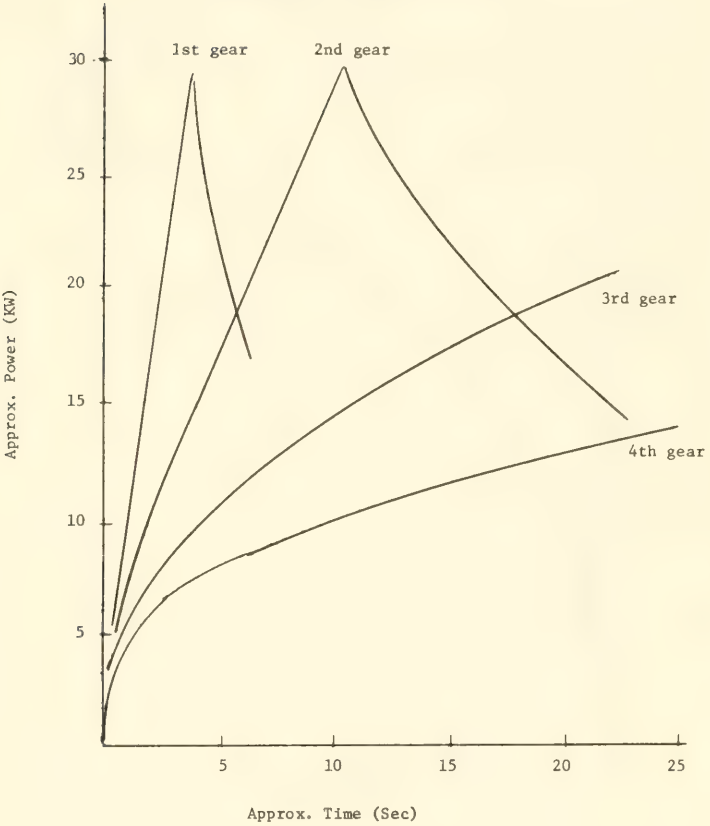


FIGURE 7

ENERGY CONSUMPTION FOR ACCELERATION

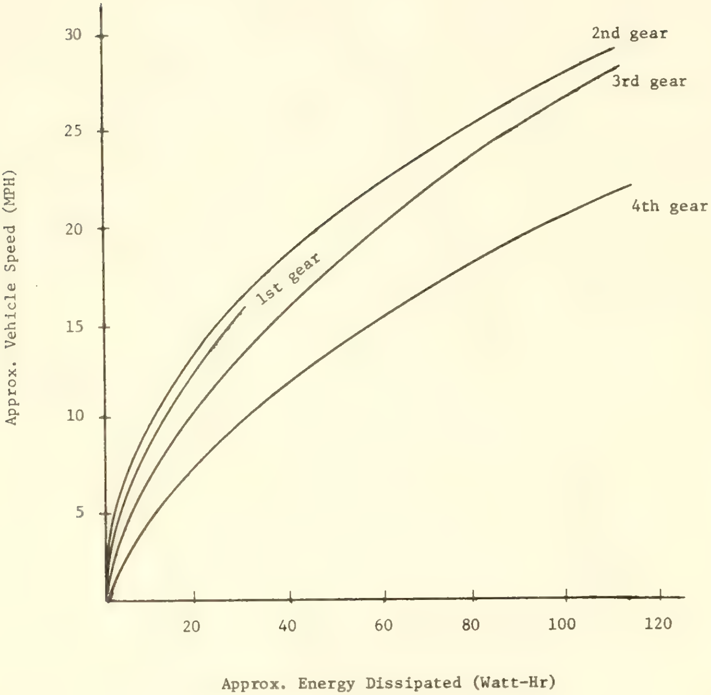
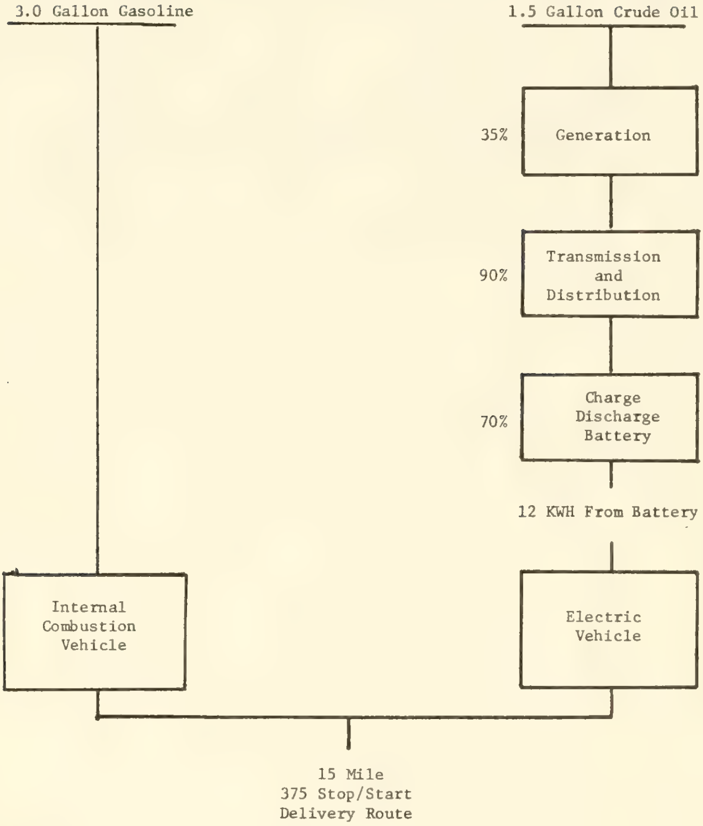


FIGURE 8

ENERGY UTILIZATION COMPARISON



THE ELECTRIC AUTOMOBILE

To the average American the energy "crisis" has meant a gasoline shortage. Many homes were cooler than usual this past winter, partly due to a nationwide drive to save natural gas, and partly because of shortages in distillate fuel. But every driver of an automobile—nearly half our population—had some trouble getting gasoline. If gasoline continues to be scarce, what are the alternatives? What other energy sources are available to power our automobiles? Methyl alcohol or substitute gasoline made from coal are possibilities, so also is electricity.

Electric automobiles existed long before gasoline was available, almost half a century in fact. Records show that 1575 electric automobiles were built in the year 1900 compared with only 939 cars equipped with gasoline engines. Electric automobiles were popular with the ladies, who had difficulty in starting the cranky piston engines of that day. Later, after the self-starter had been invented and automobile engines had been improved, electric vehicles could not survive. By 1930 they had become museum pieces. Now, gasoline shortages and environmental problems have led to new interest in a family car operating on kilowatt-hours rather than on petroleum products.

Why did electric automobiles lose out in competition with gasoline? Simply because of the limitations of batteries. Let's look at the energy tied up in a tank of gasoline compared with that in a storage battery. A 20-gallon tank of gasoline can provide about 2.4 million Btu's; lead-acid storage batteries weighing the same as that tank of gasoline can provide only some 7700 Btu's, or about 2-¼ kilowatt-hours. The ratio, then, of energy in a tank of gasoline to the energy in the same weight of conventional shortage batteries is more than 300 to 1. But, an automobile engine can convert only about a fifth of the energy in the gasoline into driving power, while the electric motor can produce motive effort from nearly *all* the electricity delivered by a battery. Even with this advantage, electric drive suffers badly in performance compared with gasoline.

The problem, then, is how to provide an automobile with enough electricity to give it the same range and performance as a car burning gasoline. So far, that problem hasn't been solved. Many exotic battery systems are being developed in the laboratory, including zinc-air rechargeable cells, hot sodium-sulfur, lithium-sulfur, and lithium-chlorine secondary batteries, and other high-performance electrochemical devices. None as yet has proved practical for public use. Rechargeable batteries such as nickel-cadmium, iron-nickel, and silver-zinc are far too costly. Only the conventional lead-acid battery, similar in contruction and chemistry to the starting-lighting-ignition (SLI) battery in today's automobile, has proven practical. Essentially all the electric vehicles on the road today—some 50,000 in England alone—are powered with lead-acid batteries.

Let's assume, then, that we'll use lead-acid batteries to power our passenger car. Experience shows that an electric automobile in city traffic at speeds up to 35 mph uses about ¼ kilowatt-hour per 10 miles. Let's assume further that our car with passengers weighs 3000 pounds, with half that weight allowed for the battery. The very best lead-acid batteries today can deliver 15 watt-hours per pound if discharged over 20 hours, so our battery can deliver, at the maximum, 22.5 kilowatt hours. But since our battery will be discharged over a 1- to 2-hour period, its capacity will be about halved. Thus the useful available output at most will be 11 kilowatt-hours from that 1500-pound battery pack. And since the car weighs 1½ tons, thereby using 0.375 kilowatt-hour per mile, it will have a maximum range of only 30 miles at 35 mph with a fully charged battery.

If, instead of 35 mph, the driver elects to use a freeway at 55 mph, his range would be cut in half, or perhaps to 12 to 15 miles per charge.

Costs? There will be no essential difference between the cost of present gasoline-power systems and an electric motor, its controls, and its simplified drive train. The battery, however, will be an additional cost. Based on prices paid by the Government presently for lead-acid batteries, the least expensive one is a 12-volt, 200 ampere-hour-capacity SLI type costing $48. Since each such battery can deliver about 2.4 kilowatt-hours at a 20-hour discharge rate, ten batteries would be required for our car, for a total battery cost of $480. Because these batteries can provide about 500 discharge cycles, with 30 miles each cycle, the battery should be good for 15,000 miles. Hence, the cost for the battery alone would be about 3 cents per mile. Power costs at 3 cents per kilowatt-hour to the battery charger and an overall efficiency of 50 percent from power in to power out would add up to about 2¼ cents per mile. Thus, total operating costs, including battery replacement, would approximate 5 to 6 cents per mile, or about twice today's cost for gasoline vehicles of comparable performance with gasoline at 50 cents per gallon.

What's the status of electric automobiles today? Of the 50,000 electric vehicles in England, most are commercial, not passenger cars. In the United States, the first recent batch of electric automobiles were put on the market in the mid-1960's. About 50 cars were sold. Most went to public utilities as demonstration vehicles. Greatly renewed interest has arisen recently, with at least four small, but aggressive, companies active in the field. The smallest vehicle is aimed at retirement centers with a motorized three-wheel vehicle to cost under $1200. Another is not much bigger than a golf cart, weighing 1100 pounds, seating two passengers, and costing about $2100. The largest vehicles available are built on conventional chassis and look much like ordinary automobiles, with room for four passengers. Their claimed performance ranges up to top speeds of 65 mph for short periods, but with an expected speed of 40 mph for 30 to 45 miles. Costs vary between $4000 and $8500 for such electric automobiles.

The Postal Service presently is testing electrically powered mail-delivery trucks with the intent to have 30 prototypes built if the tests are satisfactory. Later, Postal Service would expect to be able to absorb up to 3000 vehicles a year.

The American public will find it difficult to shift its preference from the high-performance, high-powered machines from Detroit to the comparatively feeble electric car. Yet, as the second car in the family, intended only for in-town driving, an electric automobile makes good sense. For shopping, for trips to the office, or for any short drive on city streets, an electric car is quite suitable and certainly far more practical than its gasoline-guzzling cousin.

The expected future shortage of gasoline may well lead to more than a rebirth of interest in electric automobiles. Electric automobiles, though still expensive considering what they can do, are available today for in-town driving. With sufficient demand by the public, the resurging higher production and lower cost could bring the electric car back as a major factor in personal urban transportation.

WILLIAM T. REID.

Battelle
Pacific Northwest Laboratories

The Energy and Resource Conservation Aspects of Electric Vehicle Utilization for The City of Seattle

THE ENERGY AND RESOURCE CONSERVATION ASPECTS OF ELECTRIC VEHICLE UTILIZATION FOR THE SEATTLE AREA

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Prepared for

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THE ENERGY AND RESOURCE CONSERVATION ASPECTS OF ELECTRIC VEHICLE UTILIZATION FOR THE SEATTLE AREA

INTRODUCTION AND SUMMARY

The increasing concern for the environment, in particular air quality, is leading to the curtailment of many of the old accepted practices, such as the backyard burning of trash and leaves. The imposition of air quality standards and consequent emission standards for stationary and mobile sources are having some conservation ramifications as well as some possible logistic problems for energy suppliers. Of particular interest is the assessment of the possibilities of introducing the electric automobile in Seattle and the consequences to the Department of Lighting.

Battelle-Northwest has undertaken the assessment of the introduction of the electric car into the Seattle area and the specific impacts on the Department of Lighting of Seattle. The study was approached in several steps:

- System Technology Assessment. In this step the state-of-the-art and future trends are examined. It is found that the current state of technology cannot supply a vehicle that competes with an internal combustion (IC) engine-powered automobile in all aspects of performance simultaneously. With specially designed vehicles one or more aspects of the electric vehicle can be made to compete favorably, but not all.

  The future (our horizon was 1990) however looks more promising. The key item is not surprisingly the state of battery technology. Currently, only lead-acid batteries are being used on a commercial scale, but they suffer from weight problems as well as the concurrent life (charge-discharge cycles)--energy density--power density problems. Research is proceeding at several places aimed at providing simultaneously the capability of long life under deep discharge conditions, high specific energy and high specific power. Other batteries are being developed which promise to become economically feasible. Hence some optimism is warranted in expecting the entry of the electric vehicle into the consumer market. The battery situation is summarized very well by the Boeing Co.(1)

A number of things are happening which could accelerate the development of electric cars and some which may retard them; for instance, the coincident imposition of stringent air quality standards and the rising price of petroleum fuels will make the economics of the electric car better, at least relatively. The economic comparisons generally found in the literature suffer from overoptimism on the part of the authors who are advocates of the electric car; however some adjustment to update the studies or to put them into the Seattle City Light service context shows the electric car to be about 15 to 16% more costly to own and operate under current conditions. The difference could disappear quickly if gasoline prices double or triple. On the other hand, the trend to smaller cars and the development of more efficient IC engines [Honda CVCC or the Ford stratified charge (two versions of the same idea)] may delay or limit the growth of the electric car market.

A number of possible artificial limitations such as an outright ban on IC engines in Seattle were not examined because such a ban would automatically make a market where none had existed. The goal of the Department of Lighting as embodied in its specifications of an electric vehicle is to have a competitive vehicle, hence artificial limitations were not considered.

- Impacts--Resources and Environment. In this task the impact of the entry of the electric car into the Seattle area on the resources and environment was evaluated. It is found that, as far as resource conservation is concerned, the situation is, at worst, a standoff: an electric car powered by coal or nuclear generation versus an IC engine car powered by gasoline (17.5% efficiency for electric and 16% efficiency for IC engine), and at best the electric car is more conservative by 25% and up, depending upon the assumptions used to characterize the cars. For comparable cars the comparison would be 9850 Btu/mi for the IC engine car and 6700 Btu/mi for the electric car (electricity supplied by a thermal generating station at an efficiency of 33 1/3%). The saving is clearly 31% of the fossil fuels. The wide variation in efficiencies obtainable with both sorts of cars, however, will make it unlikely that any arbitrary choice of vehicles for comparison will yield this exact result. (For details, see discussion in latter part of this report concerning "net impacts.") The more stringent the air quality controls and the expected degradation of IC engine performance the better the electric car appears. See Table 1.

The potential for local pollution abatement is made uncertain by the uncertainty in the projected vehicle population and the required emission characteristics in the future. The electric car is assumed to be pollution free. Thus, if the electric car fraction of the vehicle population is in 20 to 40% range as predicted then the local abatement of the residual pollution is in the same range. Our projections are for 1990. Thus the number of autos not meeting the 1976 standards should be very small since the 14-year interval 1976-1990 is about twice the average life of the current IC engine car. The residual pollution from autos should be well within the required air quality standards by the time that a signficant number of electric cars are present.

Area pollution associated with the generation of electric power will be marginally significant under our assumptions; 55,000 autos making an average of 24 miles round trip per day, would require approximately 806 megawatt-hours/day. Restriction to off-peak battery charging indicates a capacity requirement of approximately 100 megawatts. This would not be a very large additional load. Even if it is provided with thermal generation (coal or nuclear), the impact would be small or at least acceptable due to emission controls on the plants. In any event it would appear that the additional load could be comfortably accommodated by the current plant and expected additions by 1990.

- Cost/Performance Analysis. In order to forecast a market for the electric cars it was necessary to determine the relative costs of electric vehicles and the potential competitors. Some schemes such as turbines and external combustion (steam or similar) engines did not appear to be significant competitors in the time frame examined. Under some conditions, urban mass transit systems could significantly reduce the total number of trips but would probably not impinge on the electric car market to a large extent.

- Market Analysis and Forecast. Apparently no one has made a detailed market analysis of the electric car market; that is, there is no published analysis of the sort that satisfies a professional marketer. Estimates such as "The potential market for electric vehicles will be in the area of:

  1. All second, third or more family passenger cars.

  . . . etc."

  and then subsequently, ". . . the potential market may comprise about one-third of all passenger cars." No price analysis has been made and large scale analysis of this market situation is beyond the scope of this study.(2)

  Estimates following the National Power Survey analysis(3) indicate that about 75,000 electric passenger vehicles could be expected in the City Light service area if as much as one-half of the excess of the multi-car family market (all cars in excess of the first per family) were to be converted. A smaller estimate is obtained if only one-half of the multi-car families buy only one electric car, 45,000. Still another estimate is obtained by examining the trends in vehicle size and weight. As of 1970, vehicles weighing 2,600 pounds and under comprised 16.3% of auto sales or a bit over 8,000 sales per year in the City Light service area. If their life is also about 8 years, there would be a total of about 64,000 such cars in the 390,000 car population estimated for the Seattle City Light service area. The proportion however is rising and will probably double (to 33%) by 1990. Hence, the potential market for the smaller vehicles in the City Light service area will be about 200,000 cars. Penetration of this market will depend upon relative prices. The expected higher cost of the electric car versus a competitive IC engine car will limit this market approximately 20% or 40,000 cars. The range of estimates therefore is from 40,000 to 75,000.

SYSTEM TECHNOLOGY ASSESSMENT

BACKGROUND

The need for a simultaneous solution to the energy and pollution problems has resulted in considerable national and world effort toward re-evaluation of currently used energy conversion systems. Since the gasoline fueled IC engine is the largest single emitter of CO, NO_x, and unburned hydrocarbons (UHC) and consumes a major portion of the petroleum used in the U.S., it is obvious why it has come under severe scrutiny.

Several alternates to the IC engine have been proposed and studies conducted in attempts to characterize these alternate systems in terms of pollutant emissions relative to the IC engine. Recent awareness of impending fuel shortages have emphasized the need for efficient energy utilization and the need for studies which will characterize the energy use of propulsion systems currently being proposed as alternates to the IC engine. The most fundamental approach to comparing the overall efficiency of energy use for two different types of propulsion systems requires a definition (or measure) of overall efficiency in terms of total useful output divided by total direct and indirect energy inputs. An alternate approach is to define the efficiency of each energy conversion component or process in the chain connecting raw fuel input to useful output. These sub-efficiencies can then be used to calculate the overall efficiency of the system. Studies to date have usually involved a combination of these two approaches.

A breakdown of energy inputs, energy outputs, and measures of efficiency will now be discussed briefly. Valid methods of comparing the electric car and the IC engine car will also be touched on briefly.

DIRECT ENERGY INPUT

IC Engine. Direct energy input to the IC engine auto is the chemical energy in the form of fuel added to the tank. (Only gasoline will be considered to simplify the discussion.)

Electric. Direct energy input to the electric auto is the electrical energy input to the battery during charging.

INDIRECT ENERGY INPUT

IC Engine. For the IC engine auto, indirect energy can be divided into two categories. In the first category are energy inputs related to the production of petroleum, the refining of petroleum, and the transportation and distribution of gasoline. The second category involves energy inputs not related to the base fuel--gasoline. These are energy inputs for the manufacture, transportation, distribution, and sale of autos in addition to that required for repairs, insurance, highways, etc.

Electric. For the electric vehicle a similar division can be made. In the first category are the energy inputs related to the electricity used to charge the battery. In the second category are those indirect energy inputs used for manufacturing, etc., which are similar in type to the second category mentioned above for the IC engine. The magnitude of the second category indirect energy inputs would appear to be about the same for both the electric and IC engine cars. (A possible exception would be the indirect energy inputs for the manufacture of the basic propulsion plant and certain parts of the drive train and inputs for maintenance and repairs.) Detailed analysis beyond the scope of this study would be required to verify that this is so.

USEFUL OUTPUTS

The useful output of the automobile from a thermodynamic standpoint is the work output that overcomes the road load and auxiliary loads used to insure safe, convenient, and comfortable transportation. (The latter includes lights, heater, air conditioner, power brakes, power steering, etc.) The road load is made up of aerodynamic drag, rolling resistance, accelerational loads, and gravitational loads imposed when climbing grades.

EFFICIENCY

The energy utilization efficiency is the useful work output required to overcome the road loads and auxiliary loads divided by the total energy input over a given driving cycle. (Here indirect inputs of the second category must be prorated over the life of the auto in miles.) Various other methods of measuring efficiency have been and continue to be used. From these methods come such terms as miles/gallon, Btu/mile, etc. Such measures of efficiency can be useful provided some information regarding the road and auxiliary loads and the driving cycle are known--and provided some means of estimating indirect energy inputs is possible. If this information is known, then some comparison to other systems and resulting efficiencies may be possible.

METHOD OF COMPARISON

In order for a comparison between competing systems to be meaningful, the comparison must be equitable. At a first cut it would appear that a comparison between an electric car and an IC engine car would require the following:

(a) Equal curb weight
(b) Equal passenger and cargo space
(c) Comparable performance characteristics that would accomodate a reasonable driving cycle
(d) Adequate range
(e) Evaluation over the same driving cycle
(f) Equal road load.

Some types of propulsion systems lend themselves to basic automobile changes that could result in better overall efficiency because of the size, weight and geometry of the propulsion system. It does not appear that this will be the case with the electric car as compared to the IC engine car. It is difficult to imagine that reductions in curb weight, road load, or improved cargo space could be obtained with the electric car and not also with the IC engine car--at least with current and projected battery technology. The above, therefore, appears to be a fair and reasonable basis for comparison of these propulsion systems.

REVIEW OF PREVIOUS STUDY RESULTS

There are different levels at which the total energy commitment to a vehicle may be approached. A very detailed accounting for all the direct and indirect energy for the automobiles in the United States is described by Hirst.(4) In this study the direct energy inputs (See Figure 1) are traced from the refinery where 12,000 Btu/mile are produced; 2,500 Btu/mile go through the gasoline retailers, who use 200 Btu/mile and send 2,300 Btu/mile to other users involved more indirectly in the car use; and finally 9,900 Btu/mile are allocated to the automobile to go 1 mile. Indirect energy uses include:

- Energy used to produce the car, 890 Btu/mile
- Energy used to distribute and sell the car, 230 Btu/mile
- The gasoline used by all the indirect users, 2,300 Btu/mile
- Services such as parking and insurance consume 830 Btu/mile
- Repair and maintenance services consume or use 780 Btu/mile
- Highway construction (including materials) consumes 1180 Btu/mile

for a total of an additional 6,200 Btu/mile from the indirect uses and a grand total of 16,100 Btu/mile as the energy committed by all sectors of the economy to move a car 1 mile. The "car" in this case as well as the fuels are the averages for all passenger cars, all gasoline consumed and the total miles driven.

In this study we shall not be concerned with the indirect portion of the consumption because first there is no such study for the electric vehicle and secondly its hard to imagine that it would be much different for the two kinds of vehicles when taken as an average over all the variations in size, style, etc. We need only remember that about 39% of the total energy will be indirectly consumed as in Figure 1. However, estimates of direct energy utilization for electric cars and comparisons to IC engine cars have been made. The results of three of these studies are presented in Table 1 in terms of component or process efficiencies. The only indirect energy inputs considered are those associated with the production of gasoline for the IC engine car or with the generation of electricity for the battery of the electric car from the raw fuel.

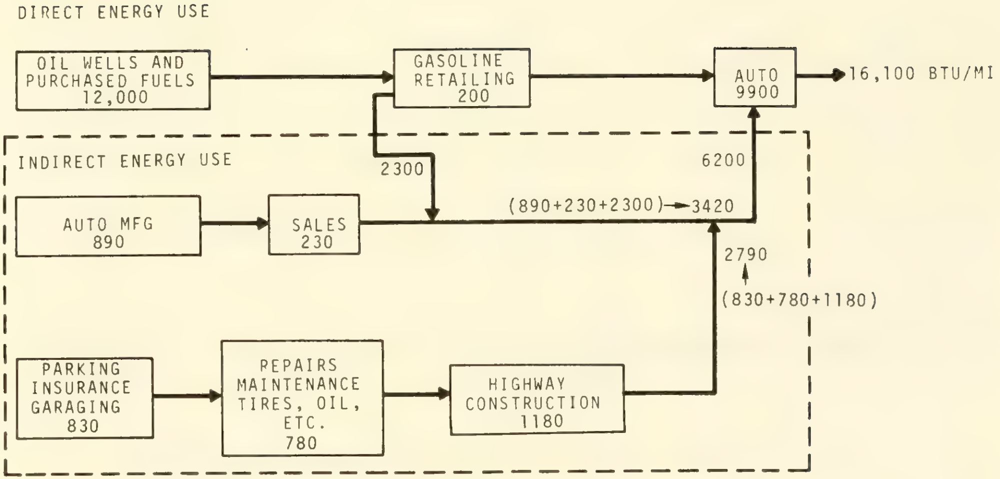


FIGURE 1. Direct and Indirect Energy Requirements for the Automobile in the U.S.

TABLE 1. Auto Component and System Energy Conversion Efficiencies - Percent

ELECTRIC	Reference(a)	Vehicle Wt	Duty Cycle	Raw Fuel	A Production	B Transportation	C Generation	D Trans-Mission and Distribution	E Battery (Charge-Discharge)	F Accessory (After)	G Motor and Control	H Transmission (Manual)	A-D	E-F	A-H
	4	–		Coal	96.	97.	36.	90.	80.	-	90.	95.	30.	64.8	19.5
	5	–	–	Coal + Nuclear	–	–	(32.5)		84.5		63.5	–	32.5	53.8	17.5
	7	3150	Fed	Pet.	–	–	35.	91.	72.	67.	65.	94.	31.8	32.	10.1
	7	3150	70 mph	Pet.	–	–	35.	91.	72.	89.	86.	94.	31.8	52.	16.5

IC ENGINE	Reference	Vehicle Wt	Duty Cycle	Raw Fuel	A Production	B Refining	C Trans. + Dist.	D Engine	E Accessory (After)	F Power Trans.	A-C	D-F	A-F
	4	–	–	Pet.	96.	87.	97.	17.5	–	70.	81.	12.	10.
	5	–		Pet.	–	–	–	25.	–	64.	–	16.	16.
	7	3150	Fed	Pet.		85.	–	(← 8. →)			85.	8.	7.
	7	3150	70 mph	Pet.	–	85.	–	(← 19.)		80.	85.	15.	13.

---

a. See References at end of report.

Hirst estimates the total energy input to manufacturing, maintenance and repairs for IC engine autos as 10% of the total direct plus indirect energy input. Therefore, unless energy inputs for the manufacturer of the battery, motor, controls, drive train, and maintenance and repair of the electric car are significantly different from the corresponding items of the IC engine car, they would be a very small part of the total energy picture and could be neglected. Since a clear definition of indirect energy inputs for category 2 pertaining to the electric car are beyond the scope of this study, they will be assumed to be the same as for the IC engine. Information developed in the future may require modification to this assumption, however it is unlikely that more than minor changes in the overall conclusions would result.

Based on the foregoing assumption, the method of comparison given in Table 1 would appear to be a reasonable method of evaluating the electric car relative to the IC engine car--provided the criteria listed before are met. References 5 and 6 do not provide sufficient information to determine if the comparison was made on an equitable basis. The studies do indicate what types of energy utilization efficiencies are being published in the recent literature. Salihi,(7) provides the most comprehensive, documentable, and equitable study reviewed; however, it appears to require some qualification. The two areas requiring further consideration in this study include: 1) IC engine car performance in terms of miles/gallon, and 2) electric battery performance.

IC ENGINE PERFORMANCE

IC engine performance used in Reference 7 was obtained from data for autos evaluated over: 1) The Federal Driving Cycle; and 2) A constant 70 mph cruise. The values used in the study were obtained from plots of average miles/gallon versus vehicle weight. A curb weight of 3150 lbs plus 250 lbs for passengers (total 3400 lbs) was assumed for the Reference 7 study and the appropriate miles/gallon interpolated from the plot. The data used was that for 1968-69 models with an added fuel consumption of 10% expected to result from emission controls required to meet the 1975-76 standards.

The values used were:

IC Engine Car Fuel Economy (Miles/Gallon)

	1968-69		Projected 1975-76	
Curb Weight	70 mph	Federal Cycle	70 mph	Federal Cycle
3150	17.1	14.0	15.5	12.7
(Plus 250 for passengers)				

If we made the comparison on the basis of the least and most efficient IC engine cars in the same weight class we might be led to different conclusions, than are drawn by Table 1, in regard to relative energy utilization efficiencies. From the plots and source data of Reference 7 we have the following spread in fuel economy for a combined vehicle weight of 3150 lbs curb weight plus 250 lbs passenger load:

IC Engine Car Miles/Gallon 1968-69 Models

Cycle/wt.	Max.	Min.	Ave.	Max./Ave.	Min./Ave.
70 mph/3400 lbs	18.85	14.7	17.1	1.102	0.859
Federal/3500 lbs					
1968	25.0	9.5	14.0	1.786	0.678
1967	17.4	9.8			

Using the Min., Max., and Average values we have the following comparisons derived from Reference 7 basic input:

Car	Cycle	IC Performance	Overall Conversion Efficiency
IC	70 mph	Min.	0.112
		Max.	0.143
		Ave.	0.13
Electric	70 mph		0.165
IC	Federal	Min.	0.0475
		Max.	0.1750
		Ave.	0.07
Electric	Federal		0.101

From the Reference 7 study, it appears that the electric car has better energy utilization efficiency. If we use the best IC engine performance data, then the difference becomes less distinguishable. The efficiency (expressed as miles per gallon) varies quite considerably both by weight and within the weight class. Figure 2 shows the characteristics of this variation. The data are misrepresented to the extent that all cars are assigned a weight class by the EPA and they are plotted as though they were of a single weight; obviously it is not so but the spread in points is indicative of the variation to be found among different manufacturers, different models by the same manufacturer, and different country of origin. The exact data are a part of the public domain and published in the Federal Register. It is not a purpose of this study to provide such identification.

The most noteworthy items from Figure 2 are:

- The fuel economy is nearly a straight line function of weight, indicated by the dashed line, until the heavy class cars are encountered.
- The spread about the average is quite wide, with minimum to maximum varying to nearly 70% of the average.

A target electric vehicle, with a curb weight of 2,500 pounds would be competing with vehicles whose gasoline mileage ranges from 17 to 23 miles per gallon. Thus an electric vehicle whose energy use is 0.5 kW hr/mile and has an equivalent gasoline mileage of 21 miles per gallon is competing in a class where the best of the IC engine vehicles is roughly equivalent to the electric vehicle in energy consumption. Since the best IC engine cars are currently available, tested and proven, it appears that these cars should be the basis of comparison to a yet unbuilt, untested, and unproven electric auto.

BATTERY PERFORMANCE

Two important battery performance parameters are: 1) specific power in watts/lb, and 2) specific energy in watt-hrs/lb. Specific power defines the rate at which energy can be supplied. Specific energy defines the

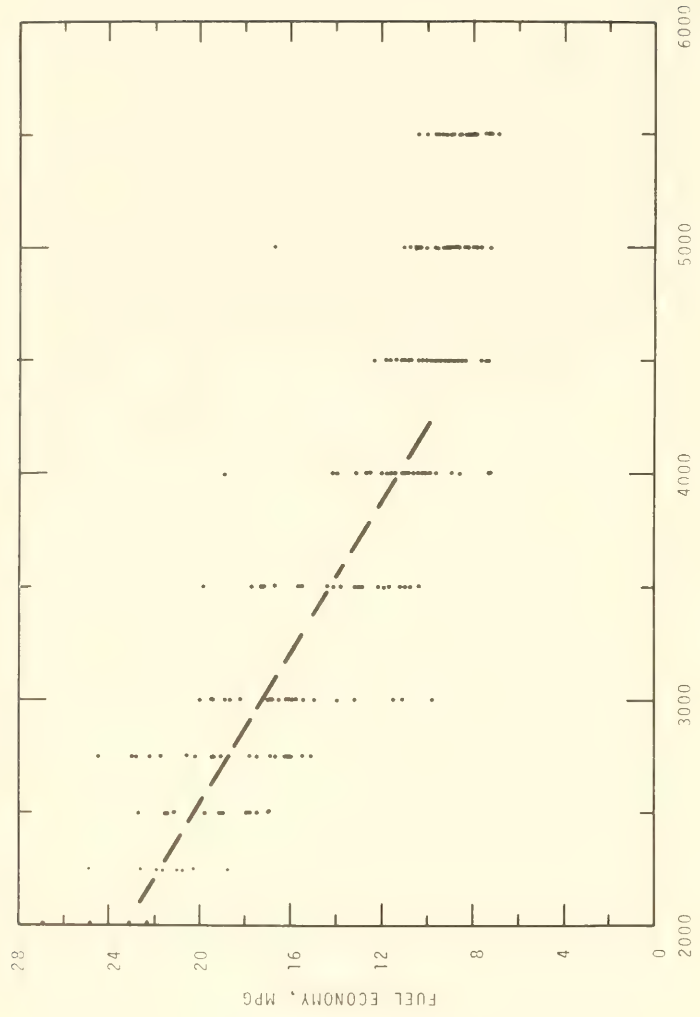


FIGURE 2. Fuel Economy by Weight Class for 1973, Automobiles Sold in the U.S., Environmental Protection Agency Data

total amount of energy that can be supplied. In 1968 Ragone(8) listed typical performance characteristics of batteries. Some improvement in performance, particularly in lead acid batteries, has been noted since then.(9) Figure 3 is a reproduction of the combined results of References 8 and 9.

If one knows the road load as a function of vehicle weight and speed one can calculate the battery characteristics required to travel a given distance at a fixed speed. The battery requirements for the Salihi vehicle are presented in Figure 4 and superimposed in Figure 5 on the battery characteristics plot. The road load characteristics are listed below the figure. Although these curves are for constant speed on level grade, three conclusions can be drawn from Figures 4 and 5 and the relations used to derive Figure 4. First, considerable battery development is required to provide combined range and speed comparable to the IC engine car at an economical price.

Secondly, adequate range and a reasonable speed for the major portion of trips made in the Seattle area can be accommodated now with the improved lead acid batteries of Reference 9, at least for trips of constant speed, level grade, and at a battery to road load efficiency of 72%. Accelerations and grades would require additional power above the load due to rolling resistance and aerodynamic drag. For example, the 3400 lb auto of Figure 4 traveling at an initial speed of 20 mph would require power density of 25 watts/lb to accelerate at the rate of 3 mph/sec in addition to that required for rolling resistance and aerodynamic drag. (Three mph/sec is the maximum acceleration used in the Federal Driving Cycle.) This type of performance seems to be nearly achievable with the improved lead acid battery.

Thirdly, some improvement can be obtained by decreasing the road load, due to aerodynamic drag and rolling resistance or increasing the ratio of battery weight to vehicle weight. The latter may result in less passenger and luggage space, unless increased structural strength can be obtained through advanced design.

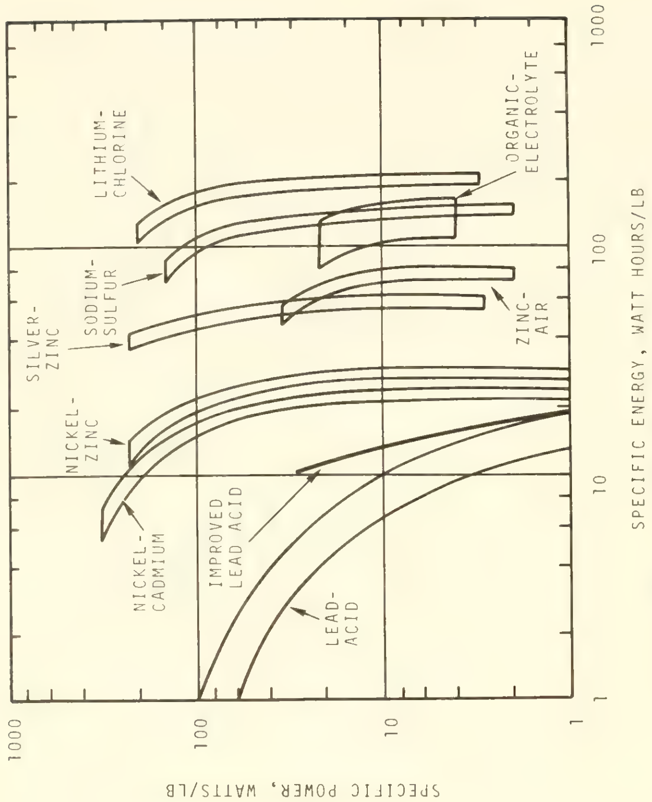
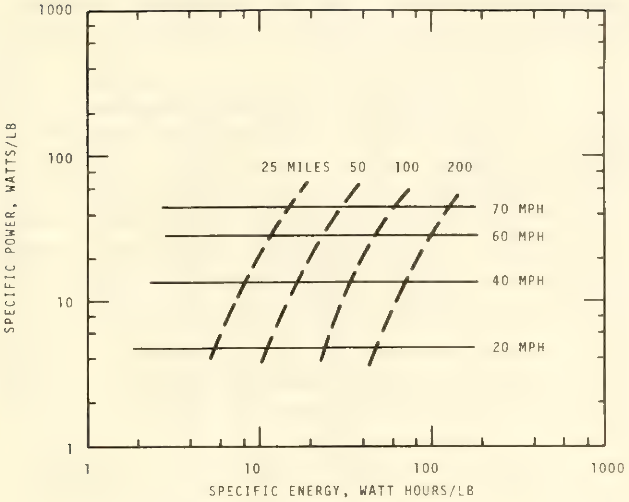


FIGURE 3. Battery Performance Characteristics



TOTAL WEIGHT 3400 LBS

BATTERY WEIGHT 750 LBS

ROLLING RESISTANCE FORCE (LBS) $= 52.3 \left[1 + 0.123 \left(\frac{S}{60}\right) + 0.0929 \left(\frac{S}{60}\right)^2\right]$
(S = MILES/HR)

$= 54.98$ @ S = 20 MPH

$= 66.41$ @ S = 70 MPH

AERODYNAMIC DRAG COEFFICIENT x FRONTAL AREA = 9

BATTERY TO REAL LOAD EFFICIENCY (INCLUDING AUXILIARIES) = 72%

FIGURE 4. Battery Requirements for the Reference Salihi Vehicle

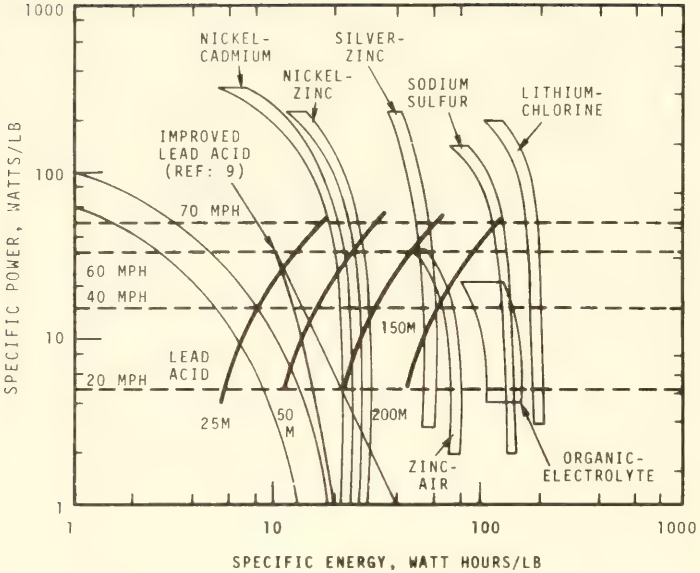


FIGURE 5. Battery Requirements (Salihi Reference Vehicle) and Battery Capability

IMPACT OF ELECTRIC CAR USE

A compact four-seater electric passenger car can be seen as a natural substitute for the family second or even third car with limited intra-urban use. A thorough review of the literature (see References) suggests that the most important single factor limiting the widespread production and distribution of small passenger electric cars is the unavailability of a high energy battery that will meet competitive performance of the traditional gasoline-powered car, yet be of light weight and reasonable price.

However, if a suitable battery package is developed, there are several factors that could cause electric car use to become a reality.

- The increased emphasis of reducing metropolitan air pollution and traffic congestion. The electric car could reduce overall abatement costs.
- Regulatory measures proposed for chronically polluted urban areas such as Los Angeles, northern New Jersey, and 15 other "critical" areas. The electric car could be used in conjunction with existing and developing rapid transit systems.
- Proposed ban of all autos by 1977 in downtown Los Angeles. Electric cars could be used as a substitute.

Though it is well recognized that there is an urgent need for a substitute for the existing internal combustion engine, there is less general agreement as to what is the best substitute. For example, does the answer lie in stringent air pollution control equipment attached to existing cars, or is it the Ford Stratified Engine? The steam engine? Or finally, is the electric car a reasonable substitute? There is a good deal of argument in the literature about the nature of transition from the existing mode of personal transportation to a desired alternative system, whatever it may be. The argument usually centers upon one or more of the following topics: (1) capital and operating costs versus performance, namely, cruising and top speed, range between battery charges, acceleration and deceleration on surface and gradients; (2) impact on the air pollution aspects of the environment; (3) general impact on the regional and national economies as a result of changing production requirements of different alternative materials used such as steel, lead, etc; and (4) the social and economic impact on the life style of the population that has to make the readjustment for the new mode of personal transportation that might impinge on personal freedom of movement.

In order to illustrate the nature of the argument for and against the use of electric passenger cars and their impact on the utilities and the environment in general, the following observations are found.

Electric automobiles, despite their many other advantages, will not compete in performance with piston-engined vehicles in the foreseeable future. While the electric cars may have adequate top speed the electric passenger car with a relatively short range could find its greatest use as the second-car-in-the family, best suited for intraurban transportation.(10)

Energy requirements for land transportation can be reduced by electrification of propulsion, especially in areas with high density traffic.

Since the actual energy requirement of electric propulsion is small when compared with the energy used by current vehicles, most of the urban motor vehicle transport and half of all the railroad transport could in fact be electrified with an increase of about one-fourth of the annual electricity supplied by utilities; this electrification could be accomplished without a massive expansion of the installed electricity-generating capacity.(11)

Given the state-of-the-art in developing electric passenger vehicles, the capability of the existing power industry, and the availability of off-peak power, it is felt that the development of the electric vehicle market will be gradual with minimum disruption of the automobile industry, the electric power industry and the petroleum industry or their suppliers.(12)

Electric vehicles may not pollute their own neighborhoods, but they draw electricity from generating stations which do contribute to the pollution problem. For the near-term, say 10 to 15 years, the IC engine with emission control may be the best compromise in the national interest, because it may prove more efficient than any other alternative.(13,14)

A recent collection of papers on Electrochemistry of Cleaner Environments published in a book form(15) emphasizes that the incentives for electric vehicle use come from at least two concerns: (1) minimization of local air pollution contributed primarily by automotive transportation, and (2) conservation of fossil fuel supplies for other uses and use of alternative energy sources, mostly nuclear power. Nuclear energy is projected to be a major contributor in the energy market near the end of the present century. Since nuclear energy is anticipated to contribute a significant portion of energy supplies in the future, battery powered vehicles could use energy generated by nuclear power and thus help conserve fossil fuels, namely coal, oil, natural gas and petroleum for other specific needs.

Following the above line of thought, Salihi(16) argues that future demand for electric vehicles will neither unduly utilize the available electricity supplies nor does it create another major source of pollution at the power generating plants. In fact, he argues that the extra power capacity needed to produce electricity for electric cars can also be used to improve the economics of power-generation systems. "On the average, the electric power industry uses only 52% of its total capacity at all times; the remaining capacity is used for the maintenance of equipment and to meet peak demands." (Discussion of SAE paper 710190, January, 1971.) Salihi also shows that use of electric vehicles, assuming a significant proportion of electricity being generated by nuclear power, would effectively reduce emissions of hydrocarbons, carbon monoxide, sulphur oxide, nitrogen oxide and particulate emissions. Conservation of fossil fuels is also stressed as a factor to ease the import-export balance. With the assumption of long-range development of high energy batteries, the electric car with its potential of high reliability, low maintenance and ease of repair, could very well capture a good share of the automotive market in the future.

A full scale transition from existing IC engines to electric passenger cars can influence and significantly change the nature of goods and services that are usually provided with the existing automotive and ancilliary industries. In an excellent exposition of various areas of concern, Dr. Netschert of National Economic Research Associates(17) has touched upon relevant issues that will and should be raised in the case of transition or complete switchover to electrified transportation. The effect upon the utility industry as suppliers of electricity is well known. Dr. Netschert comes to the conclusion that, in the end, as the derivation of the electric energy projections for transportation makes clear, the indirect route of fuel consumption via the central generating station is far superior and more efficient than the direct route of petroleum consumption in the vehicle. Even though increased use of electricity adds to the problem of controlling pollution, there cannot fail to be a net benefit for pollution abatement--a point that has already been alluded to by other sources. Only the distribution of pollution abatement costs remains to be resolved.

Such a transition would cause a decrease in the revenue of oil refineries and a corresponding increase in the battery manufacturing industry. This would be perhaps more gradual than sudden. Dr. Netschert points out that "after all, the rise and fall of industries is as much an inescapable part of our economic life, as the rise and fall of individuals is in our public life." This will in turn reflect in regional economic ups and downs which have to readjust to new ways of life brought about by societal demands and goals on energy and environment.

The full impact of transition to electrified transportation can be traced via petroleum industries, synthetic fuel industries, replacement parts industries, the conventional service stations, the evolution of battery industries and charging stations and, most significantly, the automotive industry and the impact on highway design and traffic problems.

In the case of the automotive industry, since the essential change is in the propulsive device, the question is who will manufacture the electric motors instead of present combustion engines. Ultimately, economics would dictate whether the Detroit auto manufacturers would let the electric equipment industry supply the electric motors or would manufacture their own for less cost. But the effect on the replacement parts market would be negative, assuming that the electric car is equipped with a simpler propulsion system that has a longer life.

In the case of any large-scale use of electric cars, Dr. Netschert points to another troublesome area--namely highway design. "It is here that the oil industry, with its close ties to the other members of the highly effective highway lobby, could raise especially troublesome political obstacles." This would only mean that a large-scale electric car usage will probably be more remote than the protagonists of electric cars would like it to be. Also, any transition would only be gradual rather than abrupt.

Finally, any changeover to electrified transportation would involve foreseeable effects on government revenues in the form of gasoline taxes and a way to counterbalance this loss of revenue by another appropriate and equitable form of tax structure. Since fuel taxes form an appreciable fraction of federal and state taxes, the evolution of a new tax to replace the old gasoline tax would naturally involve serious efficiency and equity considerations, user charges versus general taxes, increases in electricity taxes and their affect on the operation of the electric car itself. Any economic advantages of operating an electric car can be to some extent offset by additional charges on electricity and may make it very competitive with the IC engine vehicle. Only the net effect, taking into account economic trade-offs and the intangible benefits of cleaner environment, could ultimately dictate the rise and fall of electric passenger cars.

COMPARISON OF COSTS: ELECTRIC CAR VERSUS THE PRESENT GASOLINE-POWERED CAR

One of the earlier studies dealing with cost comparisons of owning and operating the present family car versus a corresponding electric car was done under contract to the National Air Pollution Control Administration by Arthur D. Little, Inc. in 1969.(18) One of the main conclusions reached in that study was that the initial purchase price of electric vehicles would be higher than the corresponding internal combustion engine vehicle. Though part of the higher initial purchase price may be offset by longer life and lower maintenance costs, it is suggested that much of the price differential be considered a social cost for the elimination of air pollution. Assuming that the electric car could cost $1,000 more than the corresponding gasoline-powered car, this extra cost allowance would permit a battery cost allowance at the rate of $0.95 per pound of battery weight. Other cost differences due to replacing the existing engine with an electric motor are overshadowed by the huge battery cost requirements. A final conclusion on whether the electric car is less expensive or more expensive to operate than the corresponding internal combustion engine on per-mile basis is still clouded by the fact that the battery life and replacement could not be predicted with any degree of accuracy (at the time of that study).

A somewhat more detailed comparison based on unit cost of operation per mile can be made on the basis of the data collected and reported by Allis-Chalmers Corporation in the Second International Electric Vehicle Symposium sponsored by the Electric Vehicle Council during November 1971.(9) In this detailed case history and economic study of the performance of electric versus gasoline-powered commuter vehicles, two types of situations were considered. These were (1) Vehicle 'A' -- new 1964 Karamann Ghia used between 1964-71 and driven 124,500 miles in that period; and (2) Vehicle 'B' -- used 1964 Karamann Ghia used between 1966-71 and driven for 48,300 miles. The two cases are similar in nature. The first case (Vehicle 'A') will be dealt with in detail for an effective cost comparison in this study, in line with other cost comparisons that follow.

The following cost data are extracted from the above study:

Cost Comparison of Operating a 1964 Karamann Ghia, by a Gasoline-Powered Engine and an Electric Motor[(a)]

	Gasoline-Powered Engine		Electric Motor	
	¢/Mile	%	¢/Mile	%
1. Capital expense Amortization	2.23	36	2.90	39
2. Maintenance (including oil and grease)	1.78	29	1.08	14
3. Gasoline fuel (including tax)	1.30	21	--	--
4. Electricity including tax (similar to gasoline)	--	--	0.96[(b)]	13
5. License & Insurance	0.85	14	0.85	11
6. Battery Amortization	--	--	1.69	23
Total Cost/Mile	6.16	100	7.48[(b)]	100

(a) Source: Reference No. 9, Table 9.

(b) On a comparable basis for the Seattle, Washington area, the number is 0.64, using parameters as discussed below, electricity at 1.0¢/kW hr and a tax of 0.44¢/mile. The total would be 7.16¢/mile.

In the previous table, capital costs of the gasoline-powered (1964) Karamann Ghia are estimated at $3,000 and the corresponding electric car at about $3,900 at 1970/1971 prices. The capital costs in both cases are amortized over 6-1/2 years. The salvage value ($300) is subtracted for cost calculations. Both the cars are driven for the same number of miles (124,500).

The maintenance costs are significantly lower in the case of the electric car. The fuel costs are made comparable by adding the gasoline tax equivalent to the cost of electricity. Battery amortization is based on kW-hr output considering: (a) 9¢/W-hr for the best available battery; (b) 12-1/2% salvage for the battery; and (c) about 0.21 kW-hr of battery output required per mile at 60 mph. The last parameter may be too low even for the best available battery considering the efficiency of electricity output.

On the basis of the above cost data, it may be inferred that even though the initial purchase price of the electric commuter vehicle is larger by at least one-third, the operating costs (maintenance and fuel) do somewhat offset this price increase, leaving a net increase of about 21% over the gasoline-powered Karamann Ghia. On the other hand, the battery amortization cost seems too low even for the best available battery today. This cost is near 4 to 5¢ per mile rather than 1.69¢ used in their cost data. But when one considers a longer life for the electric car, the capital expense should show a smaller amortization, thus indicating that the electric commuter car is probably within reach of the average consumer.

A similar but somewhat more optimistic conclusion about electric commuter cars can be drawn on the basis of electric car manufacturers cost data. For the purpose of this study, a selected number of electric manufacturers were surveyed to acquire consistent and comparable data on the operation of gasoline-powered versus electric car that is practical and yet within reasonable price range and performance. The Electric Fuel Propulsion Corporation of Detroit has introduced the 1974 X-144 ELECTRICAR for delivery during winter of 1973 and spring of 1974, and have provided comparable economic data for the gasoline and electric cars. This is a four-passenger car with a fold-down back seat for providing cargo space. The body of the X-144 ELECTRICAR is based on the American Motors Gremlin but the chassis and running gear are specially designed for an electric propulsion system with the usual accessories. The vehicle is said to have been upgraded to the level of the Ambassador Station Wagon. The main performance characteristics claimed by the manufacturer are: (a) 60 mph maximum speed on level road with fully charged batteries; (b) 50 to 100-mile range on a charge; (c) flexibility of overnight slow recharging or 80% charge in 45 minutes using a fast charger; and (d) acceleration with fully charged batteries from 0 to 30 mph in 10 seconds. The electric motor has a 20-horsepower (direct current) capacity with a 144-volt Tri-Polar Lead-Cobalt Unit used as the propulsion battery. An additional 12-volt battery is used for running the accessories.

Of particular interest is the economic comparison of owning and operating gasoline-powered AMC Gremlin versus the electrically converted X-144 which is claimed to perform comparably with the former. The manufacturer claims that on the basis of 20,000 miles per year for five years of driving in city and suburbs, the costs per mile are slightly in favor of the X-144. And further, the electric car is definitely an advantage when longer life for the electric parts are taken into account (spreading the initial capital costs over a longer life span of the car). The following calculations are used as the basis for the above optimistic conclusion.

Basis for Comparison of Gasoline-Powered AMC Gremlin
and Electrically Converted X-144 ELECTRICAR

Cost Elements	AMC Gremlin (Gasoline)	X-144 (Electric)
1974 Fleet Price F.O.B. Detroit ($) (without any options)	2,021	3,450
Propulsion Batteries (144-volt, Tri-polar)	---	500
Fuel Consumption		
Gasoline (miles/gallon)	12	---
Electricity (kW-hr/mile)	---	0.5
Fuel Cost		
Gasoline & Oil (cents/mile)	2.5	---
Electricity (cents/kW-hr)	---	1.0
Maintenance including tires (cents/mile)	2.1	1.0
Insurance & Taxes (cents/mile)	2.3	2.3
Battery Amortization (cents/mile)	---	1.0
Optional Equipment ($)	1,000	1,000

---

*Source: Electric Fuel Propulsion Corporation, Detroit, MI

Comparison of AMC GREMLIN (Gasoline-powered) and X-144 ELECTRICAR
on the Basis of 10-Year Life (with 10,000 miles per year) and
5-Year Life (with 20,000 miles per year)

	10,000 miles/year for 10 years		20,000 miles/year for 5 years	
	AMC Gremlin (gasoline)	X-144 Electricar	AMC Gremlin (gasoline)	X-144 Electricar
Annual Fixed Costs: ($)				
Car purchase price with options included:	302	445	604	890
Battery annual amortized cost: (2.5 yr life)	--	200	--	400
Total Annual Fixed Costs:	302	645	604	1290
Variable Costs per Year: ($)				
Fuel (gasoline or electricity)	250	50	500	100
Maintenance including accessories & tires)	210	100	420	200
Insurance and Taxes (federal and state)	230	230	460	460
Total Variable Costs per Year: ($)	690	380	1380	760
Total Annual Costs (Fixed + Variable): ($)	992	1025	1984	2050
Unit Costs (cents/mile)	9.9	10.3	9.9	10.2

Note: This table is calculated on the basis of the cost and performance data furnished by Electric Fuel Propulsion Corporation.

Based on unit cost calculations in the case of IC engine and electric car, the following comments are in order:

The unit cost (cents/mile) of operating the IC engine car is calculated at approximately 10 cents per mile. This seems rather low compared to other sources. For example, based on recent data published by the American

Automobile Association, the driving costs for IC engine cars are nearly 16.5 cents per mile.(19) This is based on a variable cost of 4.75 cents covering gasoline, oil, maintenance and tires; and $3.21 per day (or 11.75 cents per mile) of fixed costs including depreciation, insurance and license fees on a full-size Chevrolet Impala. The 16.5 cent cost per mile represents an average driving of 10,000 miles per year. This unit cost would be lower, about 11.2 cents, if the car is driven 20,000 miles per year.

Similarly, the unit cost of operation in the case of electric cars is extremely optimistic. It is probably based on a substantial technical improvement in the existing lead-acid battery system, or possibly use of a new battery system for providing the necessary electrical energy to meet the desired performance characteristics.

In summarizing the cost comparisons made in this section, the following conclusions can be drawn:

The two specific comparisons of electric car versus gasoline car discussed in this section, namely, (1) electrically converted Karamann Ghia, and (2) electrically converted Gremlin, give rather optimistic unit costs; around 10 cents per mile. The low unit costs in both cases are primarily due to using low battery amortization costs which appear overly optimistic compared to the most efficient batteries available today.

The battery performance characteristics for automotive power applications can be described in terms of two parameters, specific power density and specific energy density. Specific power is related to the speed of the vehicles and acceleration. Specific energy is related to the range. Using these two parameters, a number of available and potential battery systems have been compared by Ragonne as early as in 1968.(8) These comparisons provide a common denominator for testing the feasibility of any potential battery system against all other systems that are now existing or under development. In general the desired performance characteristics, namely, a cruising speed at 60 mph, or stop and go city driving (federal driving cycle), hilly terrain, etc., do demand varying specific power and specific energy requirements.

Even the best available battery at present can provide 15 W-hr/lb battery weight (or 0.015 kW-hr/lb). To achieve a range of 60 miles, the energy requirements would be around 30 kW-hr using the parameter 0.5 kW-hr/mile; and the battery capacity requirement would be around 37.5 kW-hr assuming only 80% discharge. To achieve this kind of an energy requirement with the present battery available (0.015 kW-hr/lb) would imply a battery weight of approximately 2,500 pounds. In the light of these calculations, it can be concluded that a breakthrough in battery development for electric propulsion is a prerequisite for such optimistic cost calculations to become a reality.

NATIONAL TREND IN AUTOMOBILE GROWTH AND ITS IMPLICATION FOR THE POTENTIAL ELECTRIC CAR MARKET IN THE SEATTLE CITY LIGHT SERVICE AREA:

NATIONAL TRENDS IN AUTOMOBILE GROWTH

A survey of the literature again indicates that projections of electric car usage are sparse due to the inherent limitation imposed by battery development for the passenger cars. One of the most quoted publications refers to the study done by the U.S. Federal Power Commission (Bureau of Power) for the Committee of Commerce of the United States Senate in February 1967.(3,20,21) The FPC study includes some national trends in automobile growth, possible market potential for electric cars, and possible annual sales of cars. The study is based on the supposition regarding the future growth in automobile and other vehicle use of annual sales of 13 to 17 million cars by 1985. This trend implies annual sales of 15 to 20 million vehicles by 1990. This is an apparently optimistic assumption, considering that the present sale of new cars is about 9 million annually. The expected economic parity and other merits of electric vehicles and the rising price of gasoline could influence a gradual transition of some electric cars for use as second and third family vehicles.

The The FPC study would seem to indicate that, under the above assumptions of gradual growth in the electric car industry, by 1990 the U.S. family-owned automobiles could reach the 100 million mark. Seventy million families would own at least one car, and some of these families could own two or more cars. The potential market for electric cars as second and third family cars is estimated at 30 to 38 million--about one-third of the total automobile population--by 1990. Assuming a gradual transition (i.e., gradual increase in electric car sales of 1-1/2 to 2 million vehicles by 1980; 3 to 4 million vehicles by 1990), the number of electric cars in service by 1990 is estimated to be about 14 to 17 million. This is about one-half the potential market of second and third family cars.

Since the time of the above study, there have been certain changes which indicate that the number of families (households) owning cars has in fact increased from 70% to 80% with an increase in the proportion of two and three-car families as well. Also, with the increasing emphasis on air pollution abatement being necessitated by the emissions from the transportation sector in the economy and the changes in cost and availability of gasoline, the electric car market may materialize and capture a greater share of the car market.

As indicated in the previous section, it is not certain at this stage that, purely on economic grounds, the electric car can capture a great part of the vehicle market; although a breakthrough in battery technology, accompanied by high gasoline prices and/or scarcity could make this possible.

THE SEATTLE CITY LIGHT SERVICE AREA

The Seattle City Light service area is located between Puget Sound and Lake Washington and extends from Snohomish County on the north to Renton and South 160th Street on the south. The total maximum electricity generation capabilities are: Hydroelectric Plants, 1,466,300 kW; Steam Plants, 62,000 kW, for a total capacity of 1,528,300 kW. The service area extends beyond the corporate limits of the City of Seattle and consists of nine major substations. The land area covered consists of 126 square miles and an additional five square miles of water area makes the gross service area nearly 131 square miles. The service area in 1970 contained approximately 700,000 people, about 60% of the King County population.(22,23)

The Seattle City Light service area can also be defined in terms of the approximately 200 traffic zones that comprise this region, out of a total 635 traffic zones representing the four county Puget Sound Region. These traffic zones can be further defined in terms of planning analysis zones used by the Puget Sound Governmental Conference in their on-going transportation planning and research work. Economic and demographic information available for these traffic zones are used to develop projections of electric car markets in this study. These traffic zones are also used in developing the traffic generation patterns inside and outside the service area.(24,25) These are described later in this report.

The economic and demographic information used in this study is derived from the on-going studies conducted by the Puget Sound Governmental

Conference. In the development of an Environment Management System, the Conference is developing An Activity Allocation Model and a Natural Systems Model as integral parts. These models are used to develop and test the population and employment projections which are used as input variables for the Interim Regional Development Plan for the Puget Sound region (consisting of four counties, King, Kitsap, Pierce and Snohomish).

(a) Population Projections

The Seattle City Light Service Area, consisting of about 700,000 people (according to 1970 population census), accounts for nearly 36% of the total Puget Sound Region, and nearly 60% of King County in which the Service Area is located. The urban growth in the Service Area influences, and is influenced by, the Puget Sound region.

The population and employment forecasts developed for the region by the Puget Sound Governmental Conference are described in their publications with a recent revision of the forecasts.(26) The procedures involved are briefly as follows:

The population forecasts are developed for each of the counties by the Washington State Office Program Planning and Fiscal Management (Population and Environment Section). These county forecasts developed by the state are used as control totals. Distribution of these control totals by smaller geographic areas or zones are carried out by the Conference using their Activity Allocation Model. In effect this model assigns and distributes the available potential population growth in accordance with the location of nearby employment centers, availability of urban infra-structure and developable land, and existing population density. This model corresponds in a way to the planners concept of Development Pressure Model that is often used for intra-regional distribution of population and employment. Generally speaking, these forecasts assume a continuing economic slowdown in the economy through 1975, and an accelerating economy from then through 1990.

The Puget Sound Region (consisting, of King, Snohomish, Pierce, and Kitsap Counties) is expected to grow from a population of 1,934,600 in 1970 to about 2,558,000 in 1990, representing a 32% increase in those 20 years.

Population in King County is projected to remain constant or suffer a small loss in the period of 1970 through 1975 but to increase from 1,155,000 in 1975 to 1,476,000 in 1990 representing a 28% increase over 1970. The county's largest growth is expected to occur east of Lake Washington and south of the county. The Seattle City Light Service Area itself is expected to grow from 760,000 in 1970 to about 820,000 by 1990.

The 1990 population projection for the Seattle City Light Service Area is obtained by simply adding the projections developed for each of the transportation zones that fall within the Service Area.

(b) Automobile Projections

The various steps used in developing projections of automobile ownership in the Service Area by 1990 are briefly described below:

1. Population Projections (1990) for each of the traffic analysis zones are developed by the Activity Allocation Model using the county totals as control.
2. Average Household Size (1990). The original 1961 Origin-Destination traffic patterns used in the Puget Sound Regional Transportation Study describes the household size by type of dwelling structures within each of the traffic analysis zones. The ratio of population to household by each type of structure is calculated and average household size is then calculated for the traffic zone. Projections to 1990 were developed by continuously updating the changes in the type of structures and number of households per structure type. Where specific data were not available, a county average for the structure type was used.
3. Automobile Ownership. As part of the Regional Transportation Study, the Origin-Destination study of traffic patterns was done utilizing regression techniques. One of the major findings was the correlation of number of autos per household by household size. Expansion factors by county were developed to reflect faster increase in autos compared to population on the basis of projections of auto registration and population by counties. These are utilized to develop average automobiles per household.

4. Projected Number of Households by 1990. Total population projections for 1990 were divided by average household size to develop projected number of households by each traffic zone.
5. Projections of Automobiles by 1990 were calculated by multiplying average autos per household by number of households in each traffic zone.
6. The automobile projections for 1990 estimated by each traffic zone are added for all of the traffic zones that fall within the Seattle City Light Service Area.

The basic projections of population, average household size, and autos per household by traffic zones were provided by the Puget Sound Governmental Conference as part of their special tabulation carried out for this study. Detailed discussions of the methods can be found in their publications.(42,43)

The various projections to 1990 are summarized as follows:

1.	Population Projection	820,300
2.	Average Household Size for the Area	2.666
3.	Average Autos per Household	1.275
4.	Household Projection	308,000
5.	Total Number of Autos Projected	392,300

It is interesting to note that the average autos per household for the study area is rather low, being 1.275. This reflects that there was no appreciable rate of increase in autos relative to changes in households--an assumption underlying the projections of auto registrations in King County from 1970 through 1990.

POTENTIAL MARKET FOR ELECTRIC CARS IN THE STUDY AREA

The extent and usage of electric cars depend to a large degree on the assumption that a suitable battery package would become available in sufficient quantities and there would be sufficient time lag for manufacturers of electric cars to produce on a large scale. Also, the success of electric car substitution in the place of some of the existing internal combustion engines assumes that it will equal, if not out-perform, other alternatives;

namely, gas-turbine, steam engine, stratified charge engine, or improved versions of present gasoline-powered engines. The electric car usage might have some obvious advantages such as less noise, simpler operation, and lower repair and maintenance costs over the present cars. These advantages along with the low pollution potential might well bring about the usage of electric passenger cars in this country, on the presumption that a suitable battery would be developed and mass produced. Since an adequate (for short-range intra-urban use) performing electric vehicle is nearby achievable under current circumstances, some performance improvement can be expected. In addition, the economics will improve with the increasing fossil fuel prices and the possibility of a scarcity.

In the present study, alternate projections of electric cars are developed for the Seattle City Light Service Area on the basis of several factors; namely, projected national trends in typical metropolitan areas and the characteristics of the Seattle City Light Service Area discussed earlier. These take into account such factors as projected population and household size, average number of autos per household, distributions of households by number of cars per household, and number of potential cars for electrification. The latter were developed by each of the approximately 200 traffic zones that comprise the Seattle City Light Service Area.

In this study, the year 1970 is considered as the base period and projections are made for 1990 to conform to the available statistics on vehicle trip generation matrices.

According to the Motor Vehicle Manufacturers Association of the U.S. (formerly Automobile Manufacturers Association) nearly 20% of all households in the U.S. did not own a single car; 50.2% owned one car only; 25.0% owned two cars and 4.8% owned more than two cars in 1971.(27) The proportion of households not owning a car is usually 25% or higher inside metropolitan areas, and similarly, the proportion is lower in suburban rings and outside metropolitan areas, possibly 16%. The average distribution of households with 20% not owning a car (and the remaining 80% owning at least one car) is a reasonable estimate for the study area which consists of a central city and the suburban core.

The projected number of households by 1990 in the study region is estimated at 308,000. Using the national distribution of automobile ownership by households, nearly 61,600 households would own no cars, and the remaining 246,400 households would own at least one car, some of them two or three cars. The detailed household distribution by auto ownership is summarized below:

Projected Distribution of Households by Automobile Ownership
in the Seattle City Light Service Area, 1990

	Households Having					
	No Car	One Car	Two Car	More Than Two Cars	At Least One Car	Total Households
U.S. Average Distribution (%)[a]	20.0	50.2	25.0	4.8	80.0	100.0
Seattle City Light Service Area (using U.S. average distribution)	61,600	154,616	77,000	14,784	246,400	308,000

(a) Source: See Reference 27 (p. 38)

Since the total number of automobiles projected for 1990 is 392,300 and there are at least 246,400 households owning one car or more, the potential second and third cars are estimated to be 145,900; i.e., 392,300 less 246,400 or 146,000 in round figures.

Following national trends(3,20,21) the potential market for electric cars is estimated to be about half the second and third car market by 1990. The electric car market in the study area is estimated to be around 73,000.

For the purpose of studying the impact of electric car usage on the Seattle City Light Utility operations by 1990, the range of potential electric cars may be assigned as between 40,000 to 75,000. The upper limit can be realized if there is a breakthrough in the battery development, thus making the electric car more competitive in range, not only for the second car market, but also some of the first car market.

NET IMPACTS ON THE DEPARTMENT OF LIGHTING

An assessment, based upon the foregoing analyses, of the impacts of the projected introduction of the electric car on the Department of Lighting has been made. The impacts of importance to the department are in the categories of: resource conservation, pollution abatement and operations (load).

RESOURCE CONSERVATION

From Table 1 it is seen that the cradle-to-grave energy use of the electric car, omitting the indirect energy of manufacturing and distribution, is at worst a stand-off having a net efficiency of about 16 to 17% for both the IC engine car and the electric car when a thermal generating plant furnishes the electric power. If the losses associated with the thermal generation were eliminated and the efficiency of hydro power were used instead, the electric car would look even better by a wide margin. Whether or not the substitution is valid depends upon the expectations of the department for growth and the nature of the additions to capacity to be made. Thus, if the 1990 electric auto use of energy is ascribed to hydro generation, the very optimistic result is obtained. On the other hand, if the incremental additions are to be thermal and the electric car energy use ascribed to that, then the above comparison would be valid for the worst case.

Another way of looking at the total resource use is as follows:

- 1.0 kW-hr = 3412 Btu
- An overall average energy use per mile of driving is 0.5 kW-hr/mile or 1706 Btu/mile.
- An IC engine car at 15 miles per gallon of gasoline will use 8350 Btu/mile directly and require 9850 Btu/mile input to the refinery.

(125,000 Btu/gal x 1/15 x 1/0.85 = 9850 Btu/mile)

- However, given the efficiency of a thermal generating plant of 33-1/3% (heat rate of 10,000 Btu/kW-hr), another 1.0 kW-hr of energy would be needed to supply the 0.5 kW-hr/mile for the electric car. Or, if all losses up to the battery charging are accounted for, 1.07 kW-hr must be produced, the total being 1.57 kW-hr/mile or 5360 Btu/mile. Accounting for battery charging efficiency (0.8) raises the total to 6700 Btu/mile. This corresponds to an IC engine powered vehicle which makes 21.4 miles per gallon.

  These figures are derivable from the values in Table 1 and correspond to the cars using the Federal Driving Cycle from Reference 7.

- For this example there is a net saving of about 30% in resource fuel (40% if compared with IC engine). The electric vehicle is assumed to be competitive in appointments (power assists, heater, etc.) and the IC engine vehicle is similarly equipped, but in addition has the pollution abatement equipment suitable for the 1976 air quality standards. Without such equipment it is still not easy to obtain over 20 miles per gallon from a 3000 pound automobile. It is also possible to do much better in the electric car if one gives up such amenities as air conditioning and accepts lower speeds, etc. Under such conditions performance may range from 0.2 to 0.5 kW-hr/mile, thus increasing the efficiency by a factor of 2, or about 3400 Btu/mile.

IMPACT ON DEPARTMENT OF LIGHTING OPERATIONS

The work of the Puget Sound Governmental Conference on transportation described previously was used to obtain the trip pattern for the service area of the Department of Lighting. The estimates for 1990 are used because they were available and it is expected that it will be 1990 before a significantly large number of electric vehicles will be in common use in the service area. Table 2 shows the summary of the person trips originating in the service area and ending anywhere in or out of the service area by the purpose of the trip. These trips are considered to be the trips of primary importance to the Department of Lighting since the home base of the vehicles would be in the service area and thus be recharged there. Shown also are

TABLE 2. Summary of Person Trips Originating Daily Inside and Outside Seattle City Light Service Area Based on Puget Sound Governmental Conference Trip Generation Matrix (for 1990)

	Purpose of Trip	Total Number of Person[a] Trips Originating in Seattle Service Area, Ending in Seattle or Outside	Total Number of Person[a] Trips Originating Outside Seattle Service Area but Ending in Seattle Service Area	Average[b] Vehicle Occupancy Factor (1990)
1	Home-Based Work	478,779	206,658	1.245
2	Home-Based Shop-Convenience	218,248	19,888	1.372
3	Home Based Shop - GAF	152,169	26,814	1.372
4	Home-Based School	148,661	22,951	16.72
5	Home-Based College	65,001	52,824	1.223
6	Home-Based Social-Recreation	463,559	116,675	2.367
7	Home-Based Miscellaneous	416,783	93,310	1.274
8	Non-Home-Based	562,434	97,600	1.413
9	Commercial Vehicles	243,670	36,588	1.00

(a) Special tabulation done for BNW by Control Data Corporation, Palo Alto, California, by appropriately delineating the Seattle City Light service area. (Includes intra-zonal trips that are less than one mile each.)

(b) "Forecasting Travel Patterns" by Labh Sachdev, Puget Sound Governmental Conference, Seattle, Washington. (Table A-8), 1972.

the trips originating outside the service area and ending in the service area; and the average occupancy factor for the vehicles. These are important 1) for estimating the need for service stations in the service area and 2) for estimating the number of vehicle trips.

Table 3 shows the result of the conversion to vehicle trips for those trips originating in the service area of the Department of Lighting. It is seen that there are nearly 2 million vehicle trips daily expected by 1990. The trip purposes are given in nine categories and all categories are considered. Although, if electric school buses are used, they will have a higher energy use per mile than the smaller cars assumed for other purposes; the same might be true of commercial vehicles although a large proportion of these are small delivery vans and taxicabs and thus likely candidates for conversion to electric power.

The next step is to determine the frequency versus distance of trip. These were provided also by the special compilation of the Puget Sound Governmental Conference data. Figures 6 through 15 show the frequency distributions of trip distance. In all cases the intra-zonal trips are omitted from the figures but are added into the total for analysis.

We see from Figure 15 that 97% of the trips are under 20 miles. Thus nearly all the trips are candidates for even a limited range vehicle. The median trip is a bit less than 4 miles and the average is something less than 6 miles.

We can now compute the energy requirements of the expected electric vehicle population. If we assume that the vehicles use 0.5 kW-hr/mile and travel an average of 24 miles per day* each electric vehicle will consume from its battery 12 kW-hr. For the expected population of 40 to 70 thousand this will amount to 480,000 to 840,000 kW-hr/day. For the remaining analysis we assume only the average of 55,000 electric vehicles or 660,000 kW-hr.

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* From Table 2 the total trips equal 1,881,000 and the total vehicles predicted are 390,000; the average number of one-way trips per vehicle is 4.75. The combination of 4.75 trips and an average trip length of slightly over 5 miles yields a total of 24 miles per day per car.

TABLE 3. Distribution of Person and Vehicle Trips Originating Daily in Seattle City Light Service Area by Purpose of Trips -- 1990

		Number of Person Trips(1)			Average(2) Vehicle	Number of Vehicle Trips(3)		
	Purpose of Trip	Intra-Zonal(4) Trips	Inter-Zonal Trips	Total Person Trips	Occupancy Factor (1990)	Intra-Zonal(4) Trips	Inter-Zonal Trips	Total Vehicle Trips
1	Home-Based Work	14,293	464,486	478,779	1.245	11,480	373,081	384,566
2	Home-Based Shop-Convenience	29,997	188,251	218,248	1.372	21,864	137,209	159,073
3	Home-Based Shop GAF	4,109	148,060	152,169	1.372	2,995	107,915	110,910
4	Home-Based School	29,711	118,950	418,661	16.720	1,777	7,114	8,891
5	Home-Based College	1,311	63,690	65,001	1.223	1,072	52,077	53,149
6	Home-Based Social-Recreation	39,086	424,473	463,559	2.367	16,513	179,330	195,843
7	Home-Based Miscellaneous	39,288	377,495	416,783	1.274	30,838	296,307	327,145
8	Non Home-Based Trips	52,421	510,013	562,434	1.413	37,100	360,943	398,043
9	Commercial Vehicles	22,827	220,843	243,670	1.000	22,827	220,843	243,670
	Total All Purposes	233,043	2,516,261	2,749,304	--	146,466	1,734,819	1,881,285

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(1) Source: Special tabulation of Puget Sound Governmental Conference Trip Generation Matrix (1990) done for BNW by Control Data Corporation, Palo Alto, California.

(2) "Forecasting Travel Patterns," by Labh Sachdev, Puget Sound Governmental Conference, Seattle, Washington 1972. (Table A-B)

(3) Vehicle trips are calculated by dividing the person trips by the corresponding average vehicle occupancy ratio.

(4) Number of trips that originiate and end in the same traffic zone. These trips are of less than a mile each.

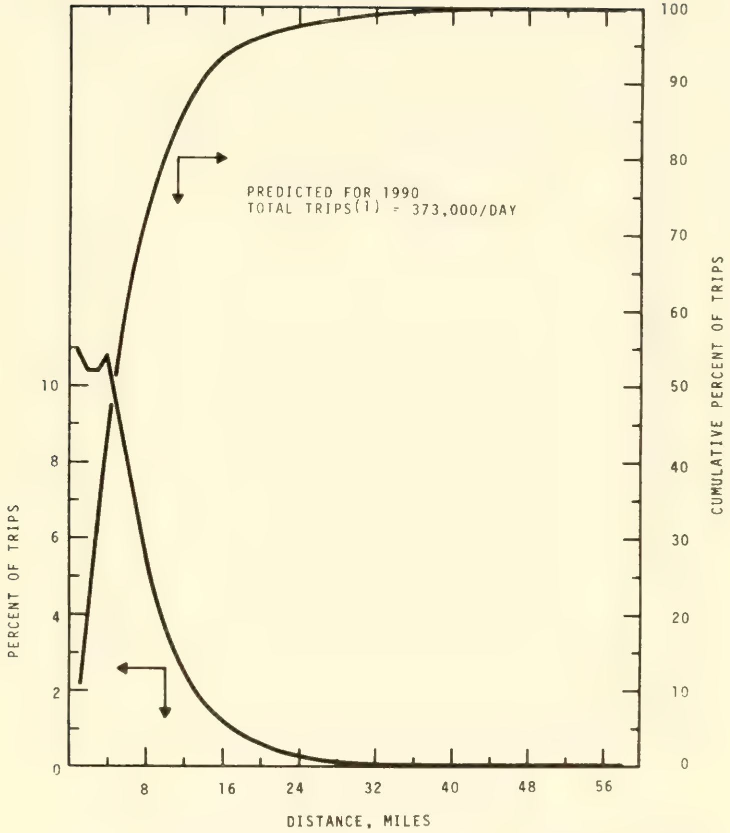

FIGURE 6. Distribution of Trips Originating in Seattle City Light Area - Purpose 1: Home-Based Work

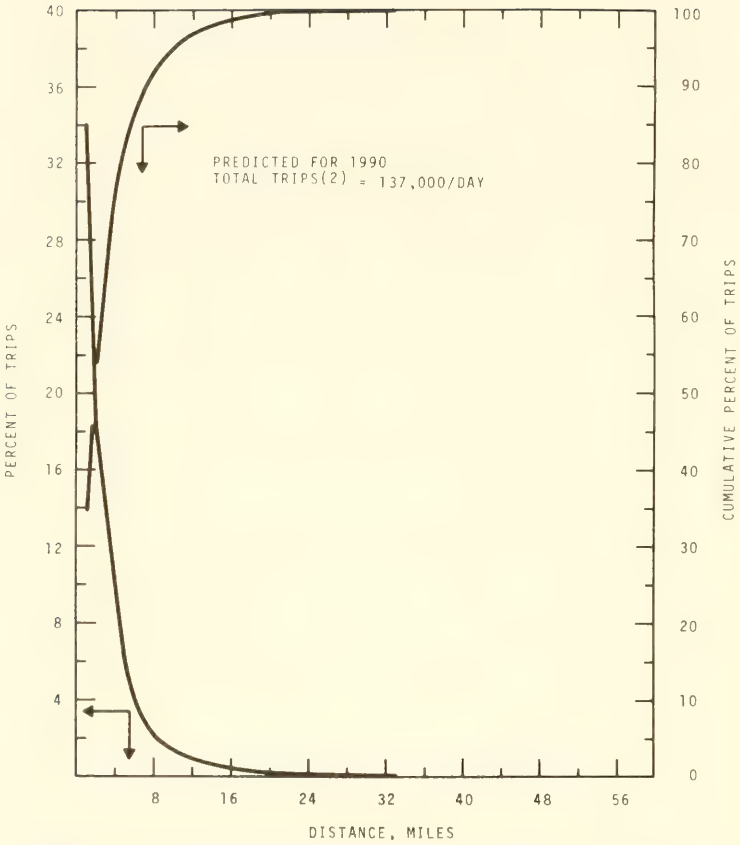

FIGURE 7. Distribution of Trips Originating in Seattle City Light Area - Purpose 2: Home-Based Shop Convenience

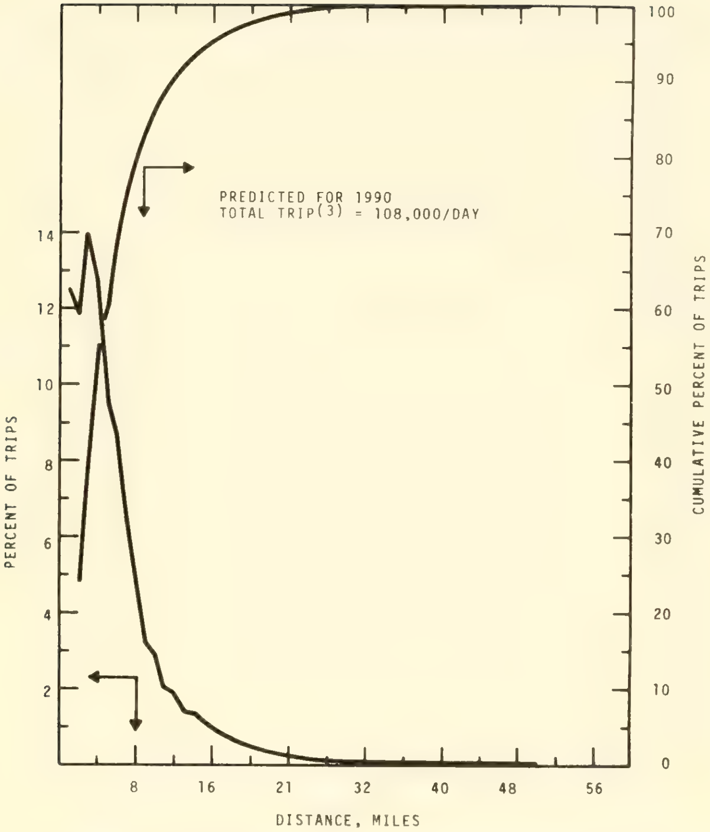

FIGURE 8. Distribution of Trips Originating in Seattle City Light Area - Purpose 3: Home-Based Shop GAF

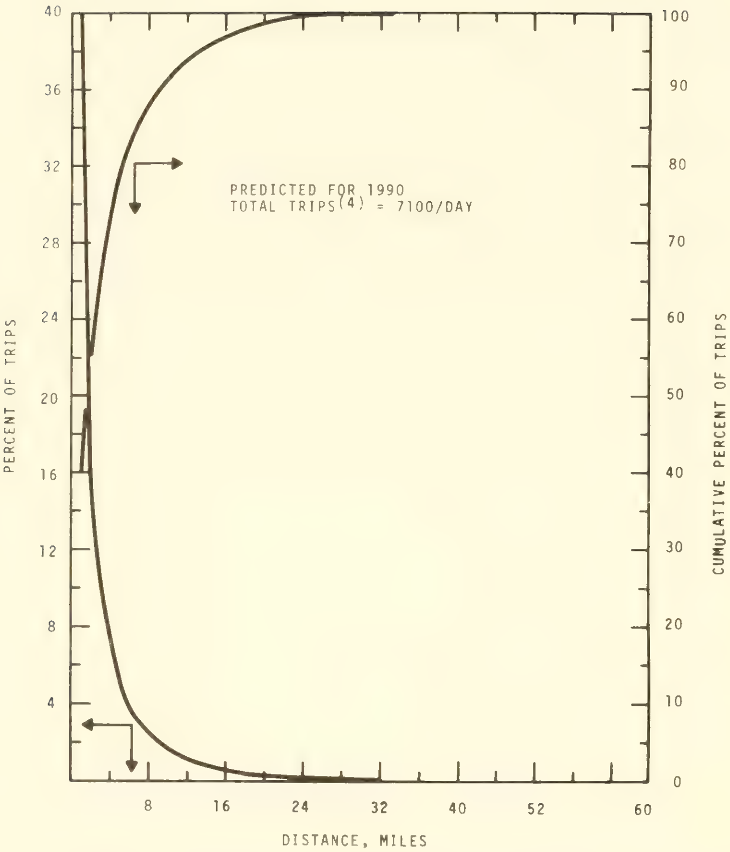

FIGURE 9. Distribution of Trips Originating in Seattle City Light Area - Purpose 4: Home-Based School

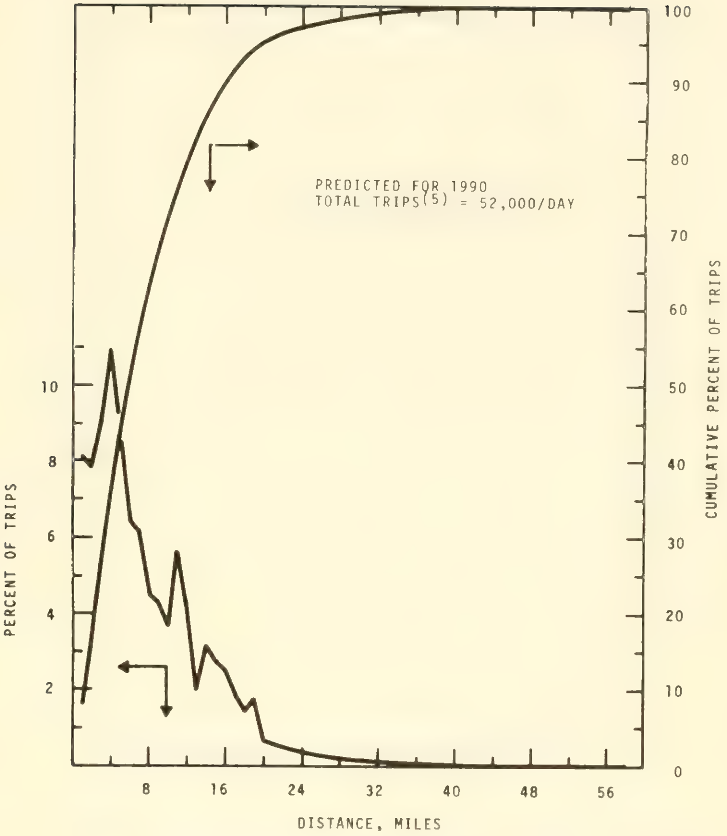

FIGURE 10. Distribution of Trips Originating in Seattle City Light Area - Purpose 5: Home-Based College

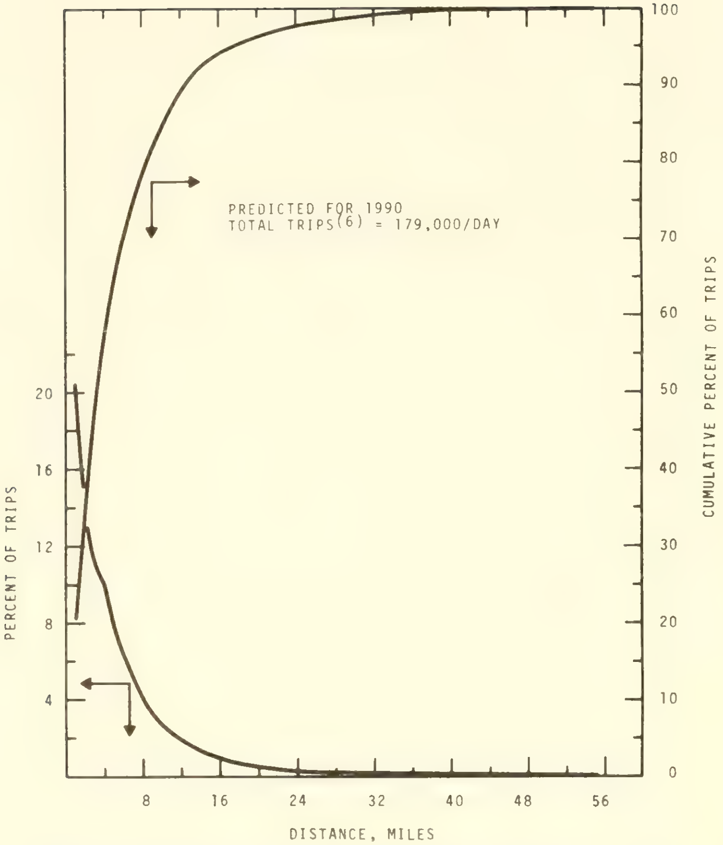

FIGURE 11. Distribution of Trips Originating in Seattle City Light Area - Purpose 6: Home-Based Social/Recreation

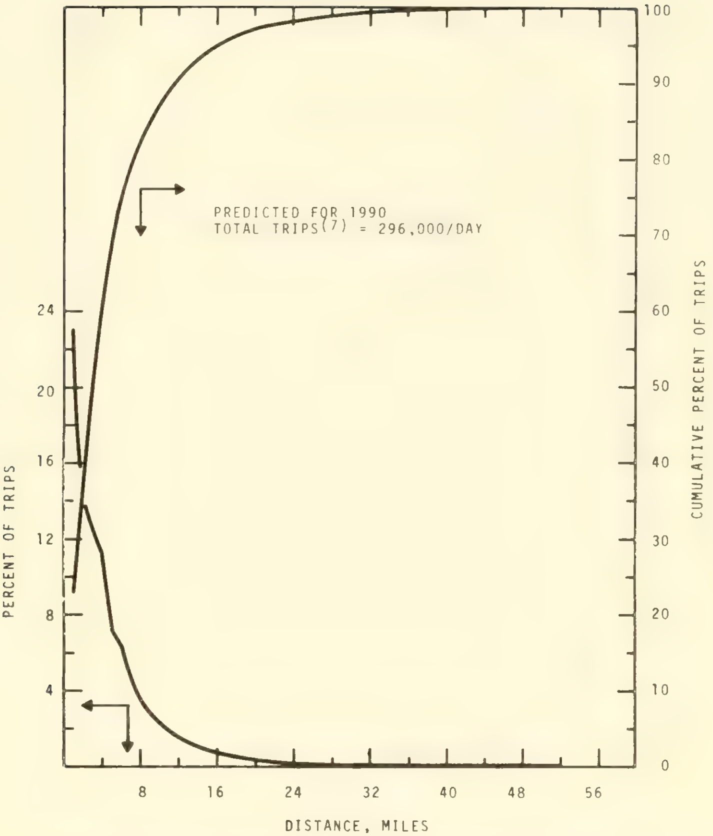

FIGURE 12. Distribution of Trips Originating in Seattle City Light Area - Purpose 7: Home-Based Miscellaneous

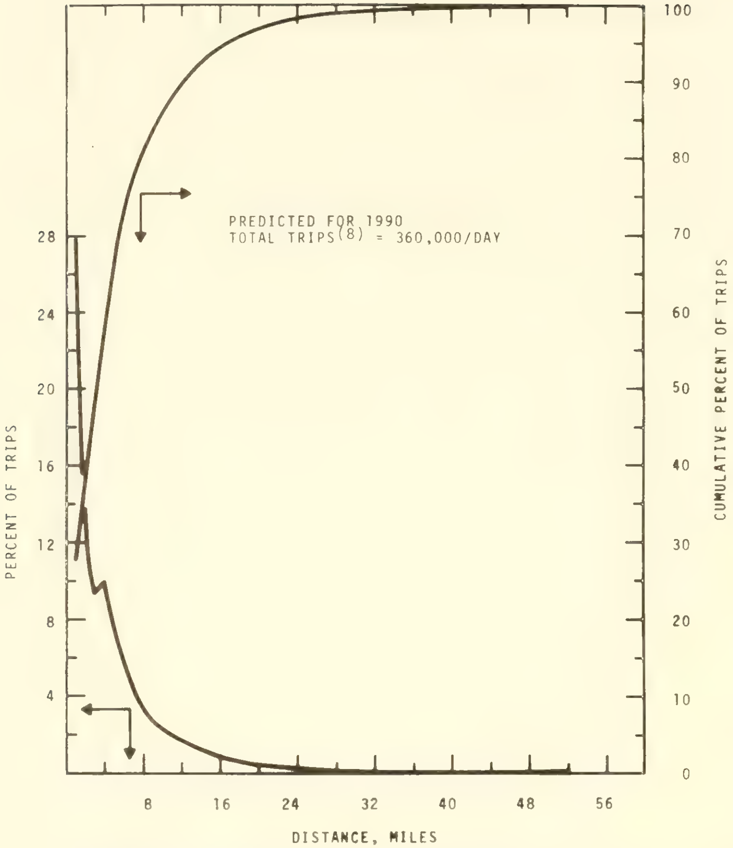

FIGURE 13. Distribution of Trips Originating in Seattle City Light Area - Purpose 8: Nonhome-Based

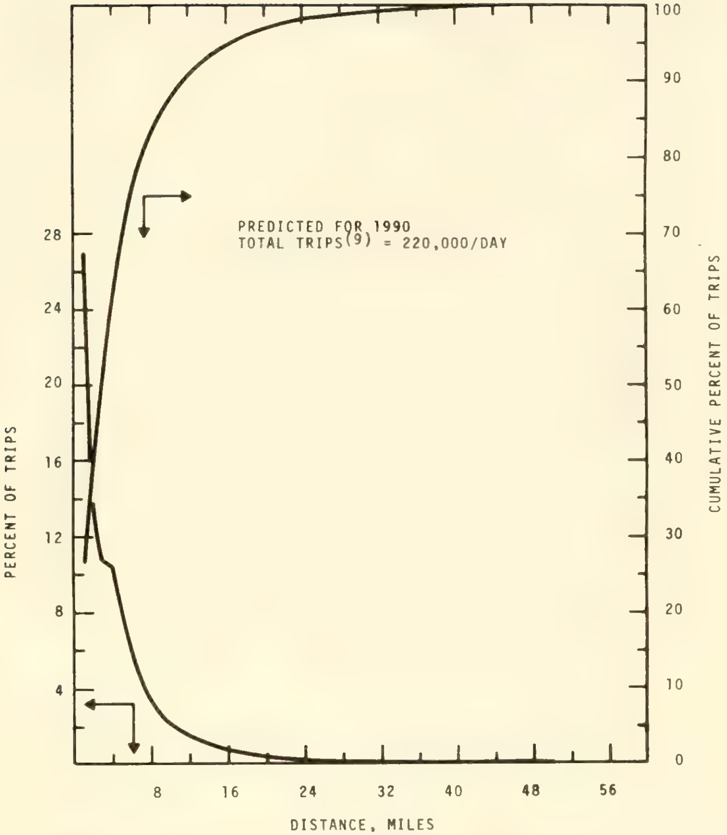

FIGURE 14. Distribution of Trips Originating in Seattle City Light Area - Purpose 9: Commercial Vehicles

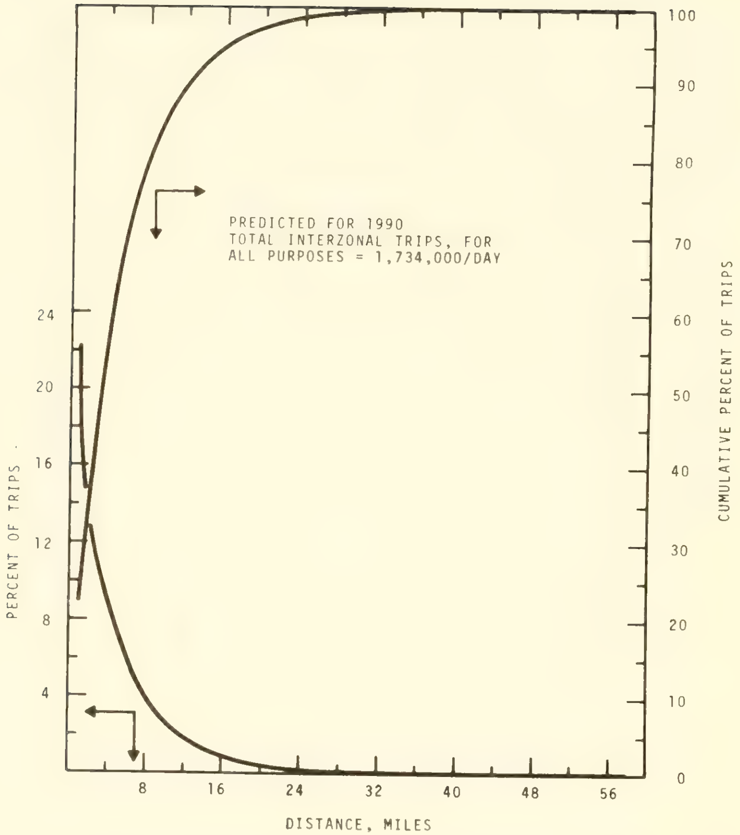

FIGURE 15. Distribution of All Trips Originating in Seattle City Light Area - Sum of Nine Purposes

From the efficiency of transmission and distribution of power (0.91) and battery charging (0.9) a total of 806,000 kW-hr/day would be required at the bus bar. In the case of the Department of Lighting whose capacity is nearly all hydro this is all that is required provided the hydro power is used on off-peak hours. The situation by 1990 could be different. For battery charging restricted to the 8-hour period from 11:00 p.m. to 8:00 a.m., the capacity requirement is about 101 MW, assuming that the charging is uniform over that period. Figures 16 and 17 show this effect on some typical daily load curves of the Department of Lighting for summer and winter. It is seen that the 101 MW are a relatively small addition to the load; there would be a small addition to off-peak load, 15 to 20% and some improvement in load factor, in the summer. It may be expected of course that in winter the use of heaters would make the average energy use higher and the effect of the electric vehicle battery charging might be about the same percentage, thus the power requirement would be higher than 101 MW.

Some additional scenarios of load pattern are possible and perhaps even desirable. For instance it has been assumed that the batteries are charged uniformly for a fixed eight-hour period; this is unlikely to occur since it would probably be better to avoid the high transient load which would occur if all of them are switched at once. In the summer for instance there would appear to be little reason to restrict the hours of charging at all since a smoother load over a longer period would be hardly noticeable. There would be required however some 55,000 relatively high power outlet installations, a factor which may be more of an impact on resources than any other.

The substitution of electric vehicle trips for IC engine trips will save 2540 barrels of gasoline per day or 712,000 barrels per year. This is equivalent to nearly 30 million gallons of gasoline. This is obtained by:

$$9850 \text{ Btu/mi} \times 24 \text{ mi} \times \frac{1}{5{,}253{,}000 \text{ Btu/bbl}} \times 245{,}000 \text{ trips/day} = 11{,}000 \text{ bbl/day}$$

or assuming 280 day/yr (assuming weekend and holiday use at 12% of the weekdays) = 3,100,000 barrels of gasoline per year.

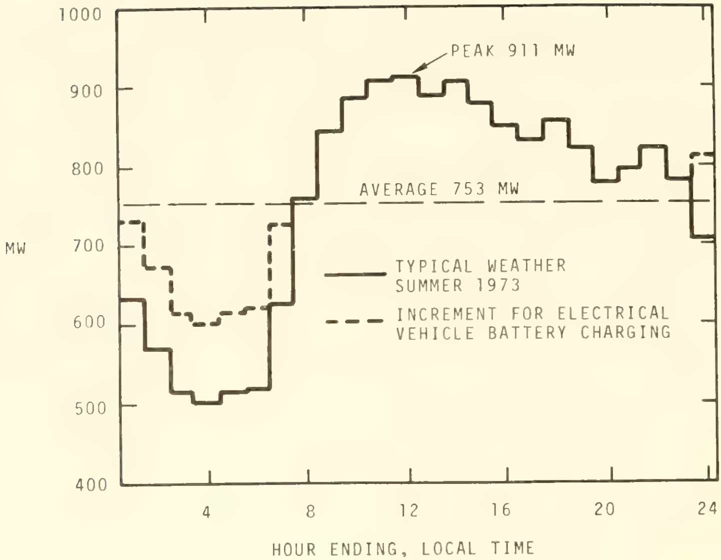

FIGURE 16. City of Seattle - Department of Lighting Daily Load Curve

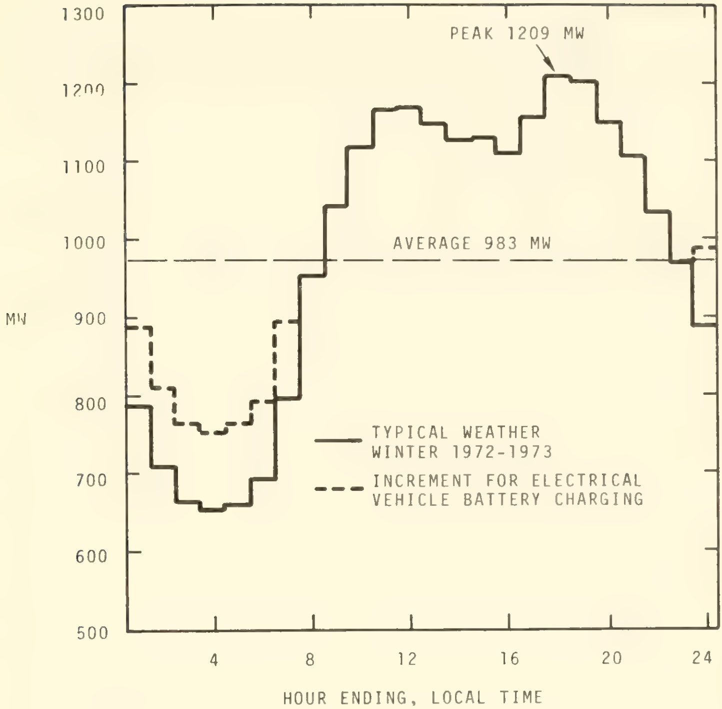

FIGURE 17. City of Seattle - Department of Lighting Daily Load Curve

POLLUTION ABATEMENT

The problem of pollution abatement needs assessment in two areas: what contribution will electric cars make to avoiding pollution from automobile exhaust emissions in the Department of Lighting's service area and what will the additional power needed for the electric cars contribute to pollution elsewhere?

The upper limit estimate of 70,000 electric cars by 1990 constitutes only about 18% of the cars estimated to reside in the service area and may be assumed to replace that percentage of the otherwise present pollution. Air quality standards however are currently mandating a drastic reduction in emissions by 1976, a lowering of 90% of nearly all emissions and some further improvement thereafter. The electric car will be essentially non-polluting locally but transfers its polluting potential to an electric power plant. While the electric power plant is a concentrated source of pollutants, many techniques are used to cut the ground level concentrations, such as high stacks, precipitators, scrubbers, etc. Looking ahead to 1980 technology when presumably the legislated air quality standards for both automobiles and power plants will be met, the emissions may be given on a per car per year basis. These results in Table 4 are from the Gordian Associates.

The numbers for the electric car represent the allocation of the power plant emissions to the individual vehicles corrected for the stack plume diffusion of effluents. As can be seen, the electric vehicle is markedly superior to the IC engine vehicle in air pollutant emissions. To the above list might be added noise in the case of the IC engine and perhaps a little radioactivity from nuclear plants for the electric vehicles. Both vehicles emit or are responsible for the emission of about the same amount of heat to the air or surface waters. The radioactivity and heat emissions are both stringently controlled for electric power plants.

The emissions given in Table 4 are currently supposed to be acceptable by 1980 air quality standards. Thus the improvement in air quality, due to the replacement of IC engine vehicles by electric vehicles, while proportional to the numbers replaced would not be considered substantial since the standards are equivalent to eliminating, not merely replacing, 90% of the cars.

TABLE 4. The Equivalent Ground-Level Environmental Pollutant Emissions (1980 Technology) for IC Engine and Electric Cars (per vehicle per year)

Pollutant	IC Engine Car	Electric Car
Total Particulates	2.73 lb	0.115 lb
Respirable Particulates	1.9 lb	0.0188 lb
Benzo(a) Pyrene Particulates	$16{,}000 \times 10^{-8}$ lb	7.0×10^{-8} lb
Sulfur Dioxide	8.54 lb	0.81 lb
Nitrogen Oxides	54.0 lb	0.41 lb
Carbon Monoxide	300 lb	0.018 lb
Hydrocarbons	44.7 lb	0.014 lb

Source: S. K. Mencher and H. M. Ellis. "The Comparative Environmental Impact in 1980 of Gasoline-Powered Motor Vehicles Versus Electric Powered Motor Vehicles: A Summary of Results," Proceedings, Second International Electric Vehicle Symposium, November 1971.

REFERENCES

1. Study of Batteries for Electric Vehicles. Boeing Aerospace Co., Seattle, WA, prepared for City of Seattle, Dept. of Lighting, Project 72-8, Final Report.

2. Kincaid, John F., et al., The Automobile and Air Pollution; A Program for Progress - Part II, United States Department of Commerce, Washington, D.C., December 1967.

3. The 1970 National Power Survey of the Federal Power Commission, Part 1, U.S. Government Printing Office, Washington, D.C., December 1971.

4. Hirst, Eric and Robert Herendeen, "Total Energy Demand for Automobiles," SAE Paper 730065, January 1973.

5. Grimmer, D. P. and K. Luszczynski, "Lost Power," Environment, vol. 14, No. 1, p. 14, April 1972.

6. Fraize, W. E. and J. K. Dukowicz, Transportation, Energy, and Environmental Issues, The Mitre Corp., M72-25, February 1972.

7. Salihi, Jalal T., Energy Requirements for Electric Cars and Their Impact on Electric Power Generation and Distribution Systems, not yet published.

8. Ragone, D. V., "Review of Battery Systems for Electrically Powered Vehicles," SAE Paper 680453, May 20-24, 1968.

9. Thiele, T. N. and D. L. Moore, "Case History and Economic Study of an Electric Commuter Vehicle," Proceedings of the Second International Electric Vehicle Symposium, sponsored by Electric Vehicle Council, pp. 344-372, November 1971.

10. Reid, W. T., Battelle Memorial Institute, "Energy Costs for Electric Cars," Hydrocarbon Processing, March 1967.

11. Grimmer, D. P. and K. Luszczynski, "Lost Power," Environment, vol. 14, No. 3, April 1972.

12. Hines, Edward, Matthew S. Mashikian and Laurance J. Van Tuyl, "Effect of Electric Vehicles on the Power Industry," Presented at the Society of Automotive Engineers, Mid-year Meeting, Chicago, Illinois, May 19-23, 1969.

13. Agarwal, P. D., "Electricity Not Such a Clean Fuel," Automotive Engineering, February 1972.

14. Agarwal, P. D., "Electric Car and Air Pollution," 710190, Automotive Engineering Congress, Detroit, Michigan, January 11-15, 1971.

15. Electochemistry of Cleaner Environments, Edited by John O'M Bockris, Plenum Press, New York-London, 1972, particularly chapter 3: Electrochemical Sources for Vehicle Propulsion, Hietbrink E. H., et al., pp. 47-97.

16. Salihi, Jalal T., "The Electric Car--Fact and Fancy," IEEE Spectrum, June 1972.

17. Netschert, Bruce C., "The Economic Impact of Electric Vehicles," Proceedings of the First International Electric Vehicle Symposium, Phoenix, Arizona, November 5-7, 1969.

18. Prospects for Electric Vehicles--A Study of Low-Pollution Potential Vehicles-Electric, A. D. Little, Inc., Cambridge, Massachusetts, NTIS Publication No. 193254, May 15, 1968.

19. "Cost of Driving Now 16 1/2¢ a Mile", The Washington Motorist, Vol. LIV, No. 10, Seattle, Washington, June 1973.

20. The Automobile and Air Pollution: A Program for Progress, Part I and Part II, United States Department of Commerce, Washington, D.C., October 1967.

21. Development of Electrically Powered Vehicles, Prepared at the request of the Committee on Commerce, United States Senate, Bureau of Power, Federal Power Commission, February 1967.

22. Seattle City Light, Annual Report-1971, Contributed by the City of Seattle Department of Lighting, Seattle, Washington.

23. Power System Information-1971, Department of Lighting, Seattle, Washington, June 1971.

24. Trip Generation Update, Puget Sound Governmental Conference, Seattle, Washington, 1972.

25. Forecasting Travel Patterns, Puget Sound Government Conference, Seattle, Washington, 1972.

26. Population and Employment Forecasts and Distributions for the Central Puget Sound Region, 1975-1990, (1972 Revision), Puget Sound Governmental Conference, Seattle, Washington, July 1972.

27. 1972 Automobile Facts and Figures, A Publication of the Motor Vehicles Manufacturers Association of the United States, Inc., Detroit, Michigan.

28. Reardon, W. A., Electrical Load Forecasting, A Review, BNWL-1964, Battelle-Northwest, Richland, Washington, November 3, 1972.

29. Gouse, S. W., "Steam Cars," Science Journal, January 1970, pp. 50-54.

30. Tomorrow's Transportation - New Systems for the Urban Future, United States Department of Housing and Urban Development, Washington, D.C., 1968.

31. Urban Mass Transportation Abstracts, Report No. UNTA-TRIC-1-72, Department of Transportation, Urban Mass Transportation Administration, Washington, D.C., October 1972.

32. William G. Kuhns, President of General Public Utilities Corporation, "A Look Ahead," a speech given at the Mid-Atlantic Electric Truck and Bus Forum, September 30, 1971.

33. Electrical Vehicles and Other Alternatives to the Internal Combustion Engine, Joint Hearings before the Subcommittee on Commerce and the Subcommittee on Air and Water Pollution of the Committee on Public Works, United States Senate, 90th Congress, 1st Session on S. 451 and S. 453, March 14, 15, 16, 17, and April 10.

34. Alternatives to the Gasoline-Powered Internal Combustion Engine, Hearing before the Panel on Environmental Science and Technology of the Subcommittee on Air and Water Pollution of the Committee on Public Works, United States Senate, 92nd Congress, 2nd Session, Serial No. 92-h33, March 14, 1972.

35. Development of Systems to Attain Established Motor Vehicle and Engine Emission Standards, Report of the Administrator of the Environmental Protection Agency to the Congress of the United States in compliance with Public Law 90-148, The Clean Air Act, as amended, September 1971.

36. An Act, Public Law 91-604, 91st Congress, H. R. 17255, December 31, 1970.

37. Automobile Steam Engine and Other External Combustion Engines, Joint Hearings before the Committee on Commerce and the Subcommittee on Air and Water Pollution of the Committee on Public Works, United States Senate, 90th Congress, 2nd Session on the Automobile Steam Engine and other External Combustion Engine Alternatives to the Internal Combustion Engine, Serial No. 90-82, May 27 and 28, 1968.

38. Gouse, S. W., "The Search for Low Emission Vehicle Propulsion," 69-WA/Ener-4, An A.S.M.E. Publication, Contributed by the Energetics Division of The American Society of Mechanical Engineers for presentation at the A.S.M.E. Winter Annual Meeting, Los Angeles, California, November 16-20, 1969.

39. Kyle, M. L., E. J. Cairns and D. S. Webster, Lithium/Sulfur Batteries for Off-Peak Energy Storage: A Preliminary Comparison of Energy Storage and Peak Power Generation Systems, Edited by John O'M Bockris, Plenum Press, New York-London, 1972, pp. 47-97.

40. Shimotake, H., A. A. Chilenskas, R. K. Steunenberg, and E. J. Cairns, "The Development of Lithium/Selenium Secondary Cells and Batteries for Implantation," Proceedings from Energy 70 Intersociety Energy Conservation Engineering Conference, Vol. 11.

41. Kyle, M. L., H. Shimotake, R. K. Steunenberg, F. J. Martino, R. Rubischko and E. J. Cairns, Argonne National Laboratory, "Lithium/Sulfur Batteries for Electric Vehicle Propulsion," Reprinted from 1971 Intersociety Energy Conversion Conference Proceedings, August 1971.

42. Project Description of a Fast-Charging Lead-Acid Battery With Improved Power Density, Department of Lighting, City of Seattle, Washington.

43. Proceedings of the First International Electric Vehicle Symposium, sponsored by the Electric Vehicle Council, Phoenix, Arizona, November 5-7, 1969.

44. Kalish, Stanley J., Kalish, Wittlinger and Associates, Inc., The Potential Market for On-The-Road Electric Vehicles, Copper Development Association, Inc., Electric Vehicle Council, May 1971.

45. Electric Vehicle News, Vol. 1, No. 4, November 1972. (Published Quarterly)

46. Your Driving Costs, 1973-74 Edition, American Automobile Association, Falls Church, Virginia.

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Components: Controllers (solid state): Emergency Power Disconnect: Gauges (energy supply)

Ford Motor Co
Transportation Systems,
19855 Outer Drive
Dearborn, Mich 48124
USA Tel 313-337-8566
Mass Transit Rail Systems

Fox Products Co
4720 N 18th St
[illegible]
USA Tel 215-329-2700
Chargers (on board), Chargers [illegible]

Franklin Institute Research Laboratories
[illegible]
[illegible]
USA Tel 215-448-1235
Engineering Research & Con[illegible]

A T Freeman
37 Percival Road
Rugby, Warwickshire
ENGLAND Tel Rugby 4213
Engineering Research & Consultants

Freeway Electric Co , Ltd
Bell Store, Okeford Fitzpaine
Blandford Forum Dorset DT11 ORF
ENGLAND Tel Child Okeford 414
Engineering Research & Consultants

Furukawa Battery Co , Ltd
No 246, 2-Chome, Hoshikawa-Cho
Hodogaya-Ku, Yokohama
JAPAN Tel Yokohama (331) 1221
Batteries (traction), Chargers (on-board) Chargers (other)

Gardner Manufacturing Co
Box 147
Horicon, Wisconsin 53032
USA Tel 414-485-4461
Trucks (burden carriers)

The Garrett Corporation
9851 Sepulveda Blvd
Los Angeles Calif 90009
USA Tel 213-323-9500
Hardware (rail systems), Mass Transit, Rail Systems

General Battery Corp.
P.O. Box 1262
Reading, Pa. 19603
USA Tel: 215-929-0771
Batteries (traction); Chargers (other)

General Electric Co
2000 Taylor St
Fort Wayne, Ind 46804
USA Tel 219-743-7431
Motors (DC Traction)

General Electric Co
2901 E Lake Rd
Erie, Pa 16501
USA Tel 814-455-5466
Mass Transit Rail Systems

General Electric Co
DC Motor & Generator Products Dept
[illegible] E Lake Road
Erie, Pennsylvania 16501
USA Tel 814-455-5466
Motors (DC traction)

General Electric Company
Industrial Control Products Dept
1501 Roanoke Blvd
Salem, Virginia 24153
USA Tel 703-389-7011
Components, Controllers (solid state) Controllers (other), Switches (on-board type)

General Electric Co
Semiconductor Products Dept
W Genesee Street
Auburn New York 13021
USA Tel 315-253-7321
Components

Gerdes Products Company
P O Box 175
Vandalia Ohio 45377
USA Tel 513-898-1367
Brakes

Globe-Union Inc
5757 N Greenbay Ave
Milwaukee Wisc 53201
USA Tel 414-228-3148
[illegible]

Gough Industrial Trucks Ltd
Clough St
Hanley
Stoke-on-Trent
ENGLAND
Tel Stoke-on-Trent 29726
Trucks (burden carriers)

Gould Distributions Ltd
20 Densley Ave
Toronto, Ontario M6M 2R1
CANADA Tel 249-7745
Batteries (traction), Chargers (other)

Gould, Inc
40 Gould Center
Rolling Meadows Illinois 60008
USA Tel 312-593-3464
Batteries (traction), Chargers (on-board), Chargers (other), Components, Controllers (solid state) Drive Systems, Engineering Research & Consultants

Gould, Inc , Century Electric Division
1831 Chestnut
St Louis, Missouri 63166
USA Tel 314-242-2500
Motors (DC traction)

W R Grace & Company
North Avenue
Northwest Industrial Park
Burlington, Massachusetts 01803
USA Tel 617-272-4060
Battery Separators

Grumman Aerospace,
Advanced Surface Transportation
Bethpage, N Y 11714
USA Tel. 516-575-0574
Mass Transit, Rail Systems, Wheelchairs & Special one-person EVs for handicapped persons

Gurgel Industria e Commercio de Vehiculos Ltda
San Avenida do Cursino 2499
Sao Paulo S P
BRAZIL
Cars (passenger, on-the-road less than 2000 lbs with batteries)

HB Electrical Mfg Co , Inc
P O Box 1466
Mansfield, Ohio 44901
USA Tel 419-747-2024
Components, Controllers (other)

Harbilt Electric Trucks & Vehicles
Logan Street
Market Harborough, Leicestershire LE16 9AT
ENGLAND
Tel: Market Harborough 2254
Chargers (other): Controllers (solid state): Controllers (other): Golf Carts: Maintenance EVs (industrial/commercial type): Trucks (burden carriers): Trucks (on-the-road): Trucks (personnel in-plant): Wheelchairs & Special one-person EVs for handicapped persons)

J M Harding (Worthing) Ltd
4 Montague Place
Worth Sussex BN14 9AT
ENGLAND
Tel Worthing (0903) 37849 & [illegible]
Component

Brad Harrison Company
600 E. Plainfield Road
La Grange, Illinois 60525
USA Tel: 312-352-3900
Connectors; Emergency Power Disconnect; Switches (on-board type)

Heinemann Electric Co.
Brunswick Pike - Rte. 1
Trenton, N.J 08638
USA Tel. 609-882-4800
Components; Controllers (solid state)

Hellectric
5919 La Jolla Hermosa Ave
La Jolla, Calif 92037
USA Tel 714-459-8974
Cars (passenger, on-the-road, 2000 lbs. or more with batteries)

Berkeley S. Hender
The Meadows, Llanvetherine,
Abergavenny, Mon. NP7 8RG
ENGLAND
Engineering, Research & Consultants

Hobart Brothers Company
Motor Generator Division
West Water Street
Troy, Ohio 45373
USA Tel: 513-339-6011
Chargers (on-board); Chargers (other)

John R Hollingsworth Co
Nutt & French Creek Roads
Phoenixville, Pennsylvania 19460
USA Tel 215-933-8951
Chargers (on-board); Chargers (other)

Hunter Manufacturing Co
30525 Aurora Road
Cleveland (Solon), Ohio 44139
USA Tel 216-248-6111
Heaters

Hydro-Catylator Corp.
P.O. Box 3648
Hialeah, Fla. 33013
USA Tel: 305-696-2504
Components

Hyster Company
P.O. Box 2902
Portland, Ore. 97208
USA Tel: 503-288-5011
Trucks (fork lift)

INACEL
Cornelio Saavedra 2720-Munro
Byebis Auresm
ARGENTINA
Batteries (traction)

I-T-E Imperial Corporation
Norristown Road
Spring House, Pennsylvania 19477
USA Tel 215-628-7400
Components; Connectors; Controllers (solid state), Hardware (rail systems), Switches (on-board type)

Ikecycle Corp , Radford Co.
Culver, Ore. 97743
USA Tel 503-456-3383
Bikes (2 and/or 3-wheel scooters), Wheelchairs & Special one-person EVs for handicapped persons

Inducto/Power
3247 Breaker Drive
Ventura, California 93003
USA Tel 805-648-4386
Chargers (on-board); Chargers (other); Engineering, Research & Consultants

Industria Nacional de Naumaticos SA
P O Box 3607
Santiago
CHILE
Batteries (traction)

Info Recherche
12 bis rue Jean-Jaures
92807 Puteaux Defense
FRANCE Tel: 776 42 01
Engineering, Research & Consultants

Integrated Battery Corp.
285 Vito Cruz Extension
Makati, Rizal
PHILLIPINES
Batteries (traction)

Intrupa
4853 N Ravenswood
Chicago, Illinois 60640
USA Tel: 312-271-1400
Brushes (motor); Components; Connectors; Controllers (solid state); Controllers (other); Meters; Switches (on-board type)

Iso-Speedic Company, Ltd
Charles Street
Warwick
ENGLAND Tel Warwick 42534
Trucks (burden carriers); Trucks (on-the-road); Trucks (personnel, in-plant)

James Research Co.
20 Willets Rd
Glen Cove, N.Y. 11542
USA Tel: 516-671-5976
Bikes (2 and/or 3-wheel scooters); Trucks (personnel, in-plant)

Japan Storage Battery Co. Ltd.
Kisshoin, Minami-ku
Kyoto
JAPAN
Batteries (traction)

Joggers, Inc
1500 Highway 315
Wilkes-Barre, Pennsylvania 18702
USA Tel: 717-825-7711
Bikes (2 and/or 3-wheel scooters), Golf Carts, Maintenance EVs (industrial/commercial type), Mass Transit, Trucks (personnel, in-plant)

E.F. Johnson Company
299 Tenth Avenue, S.W
Waseca, Minnesota 56093
USA Tel: 507-835-2050
Connectors

KW Battery Company
3555 Howard St
Skokie, Ill. 60076
USA Tel: 312-673-7710
Batteries (traction); Chargers (other)

The Kansai Electric Power Co., Inc
5 Nakanoshima 3-Chome
Kita-Ku, Osaka
JAPAN
Buses (10 or more passengers)

Dale Kelly
Box 181
Glendale, R. I 02826
USA Tel. 401-568-8494
Engineering, Research & Consultants

Kent Engineering & Foundry Ltd
Tovil
Maidstone, Kent
ENGLAND Tel: Maidstone 58361

Kinetics, Inc
529 N. Niles Avenue
South Bend, Indiana 46622
USA Tel: 219-232-1303
Wheelchairs & special one-person EVs for handicapped persons

Kollmorgen Corp
Inland Motor Div
501 First St
Radford, Virginia 24141
USA Tel: 703-639-3973
Drive Systems; Gauges (other); Motors (DC, traction)

Kollmorgen Corp
Printed Motors Div (PMI)
31 Sea Cliff Ave
Glen Cove, New York 11542
USA Tel: 516-448-1234
Controllers (solid state); Engineering, Research & Consultants; Generators; Motors (DC, traction)

Kysor of Cadillac,
Div. of Kysor Industrial Corp
1100 Wright St
Cadillac, Mich 49601
USA Tel 616-775-4681
Bikes (2 and/or 3-wheel scooters)

LaMarche Manufacturing Co
106 Bradrock Drive
Des Plaines, Illinois 60018
USA Tel: 312-299-118
Chargers (on-board); Chargers (other)

Lamb Electric Tricycles
P O Box 532
Newbury Park, California 91320
USA Tel: 805-498-5860
Bikes (2 and/or 3-wheel scooters)

Landis Battery Company
604 N. Robinson Ave.
Atlantic City, N. J 08401
USA Tel: 609-344-3113
Batteries (traction)

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Bramalea, Ontario L6T 1A1
CANADA Tel 416-677-8133
Drive Systems, Engineering, Research & Consultants, Maintenance EVs (industrial commercial type), Trucks (burden carriers), Trucks (fork lift), Trucks (personnel, in-plant)

Lansing Bagnall, Ltd
Kingsclere Road
Basingstoke, Hampshire
ENGLAND
Batteries (traction), Brakes, Brushes (motors), Chargers (on-board) Chargers (other) Controllers (solid state), Controllers (other), Maintenance EVs (industrial commercial type), Motors (DC Traction), Trucks (burden carriers), Trucks (fork lift), Trucks (personnel, in-plant)

Lawlor Industries, Inc
21 W 301 Lake St
Addison, Ill 60101
USA Tel 312-773-2740
Maintenance EVs (industrial/commercial type)

Lawnel Corporation
P O Box 206
Bluefield, Virginia 24605
USA Tel 703-326-1171
Chargers (other), Components, Controllers (other), Motors (DC, traction), Trucks (fork lift)

J A M Le Duc & Associates
300 Bassett Building
382 Springfield Avenue
Summit, New Jersey 07901
USA Tel 201-273-1088
Engineering, Research & Consultants

Lectro-Lift, Inc
2949 N W St Helens Rd
Portland, Ore 97210
USA Tel 503-223-7666
Controllers (other), Trucks (fork lift)

Legg (Industrial) Ltd
Merridale St
Wolverhampton
ENGLAND
Tel Wolverhampton 24091

Lektro, Inc
Rt 1 Box 92[illegible]
Warrenton, Oregon 97146
USA Tel 503-861-2288
Golf Carts, Maintenance EVs (industrial/commercial type), Trucks (burden carriers); Trucks (fork lift), Trucks (personnel, in-plant)

Lester Electrical of Nebraska
625 West A Street
Lincoln, Nebraska 68522
USA Tel: 402-477-8988
Chargers (on-board); Chargers (other)

Lester Equipment Mfg. Co., Inc.
2840 Coronado Street
Anaheim, California 92806
USA Tel: 714-630-2260
Chargers (on-board); Chargers (other)

Linear Alpha Corp.
P.O. Box 591
Skokie, Ill. 60076
USA
Engineering Research & Consultants

R A. Lister & Co Ltd
Dursley, Glos
ENGLAND Tel Dursley 2371
Maintenance EVs (industrial commercial type), Trucks (burden carriers), Trucks (personnel, in-plant)

Joseph Lucas (Sales & Service) Ltd
Great Hampton St
Birmingham 18
ENGLAND Tel 021-236-5050
Components, Drive Systems, Transmissions

Lyman Metal Products
15 Meadow
So. Norwalk, Connecticut 06856
USA Tel: 203-838-8491
Bikes (2 and/or 3-wheel scooters); Components

McCreary Tire & Rubber Co
P O. Box 749
Indiana, Pennsylvania 15701
USA Tel. 412-357-6600
Tires

McGraw-Edison Company
Bussmann Mfg Division
University at Jefferson
St Louis, Missouri 63107
USA Tel 314-421-1740
Components

McGraw-Edison Company
Edison Battery Division
P O Box 28
Bloomfield, New Jersey 07003
USA Tel. 201-751-3700
Batteries (traction), Chargers (on-board)

McKee Engineering Corporation
411 West Colfax Street
Palatine, Illinois 60067
USA Tel 312-358-6773
Cars (passenger, on-the-road, less than 2000 lbs with batteries), Cars (passenger, on-the-road, 2000 lbs or more with batteries), Drive Systems, Engineering, Research & Consultants, Transmissions

Magnetics International
Ohio Electric Motors Division
5400 Dunham Road
Maple Heights, Ohio 44137
USA Tel 216-662-8484
Motors (DC, traction)

Marathon Golf Car Ltd
8305 Le Creusot St
St Leonard
Montreal 458, Quebec
CANADA Tel 325-3031, 325-3931
Bikes (2 and/or 3-wheel scooters), Golf Carts, Maintenance EVs (home use type), Maintenance EVs (industrial/commercial type), Trucks (personnel, in-plant)

Maremount Corporation
168 N. Michigan Avenue
Chicago, Illinois 60601
USA Tel 312-263-7676
Alternators

Mars Industries, Inc
5209 West Broadway
Minneapolis, Minn 55429
USA Tel. 612-537-8408
Trucks (personnel, in-plant)

Maschinenfabrik Augsburg Nuernberg
c/o American MAN Corp
Postfach 50 06 20
8000 Muenchen 50
WEST GERMANY
Buses (10 or more passengers)

Mercury Clutch Div. of ASPRO, Inc.
1201 Camden Ave., SW
Canton, Ohio 44706
USA Tel: 216-456-3453
Brakes

Messerschmitt-Boelkow-Blohm GmbH
Advanced Transport Systems
P O Box 80 12 65
8 Munchen 80
GERMANY Tel 0811-60003419
Mass Transit, Rail Systems; Trucks (on-the-road)

Miami Battery & Elec , Inc
P O Box 42-202
Miami, Fla 33166
USA Tel. 305-823-1820
Batteries (traction)

Midwest Ace Battery Co
3050 Southwest Blvd.
Kansas City, Missouri 64108
USA Tel 816-931-2020
Batteries (traction)

Modern Engineering Service Co
Box 1007
Berkley, Michigan 48072
USA Tel 313-564-4860
Engineering, Research & Consultants

Monark-Crescent AB
Fack 43200
Verberg
SWEDEN
Cars (passenger, on-the-road, 2000 lbs or more with batteries)

Monroe Auto Equipment Co
One International Drive
Monroe, Michigan 48161
USA Tel 313-241-8000
Components, Hardware (other)

Monterrey Chloride, S A. DE C V
Av Washington #404
Guadalajara, Jalisco
MEXICO
Batteries (traction)

Montgomerie Reid, Ltd
Bramley, Basingstoke
Hampshire RG26 5DW
ENGLAND
Tel Bramley Green 444 (STD 0256 86)
Trucks (burden carriers); Trucks (on-the-road); Trucks (personnel, in-plant)

Morganite, Incorporated
P O Box 347
Dunn, North Carolina 28334
USA Tel 919-892-3127
Brushes (motor)

John Morris Electrical Engineering
Vulcan Road, Bilston
Staffordshire WV14 7JN
ENGLAND Tel Bilston 43341
Components

Morrison Electrical Engineering Ltd
Ashley Crescent
Portsmouth Road
Southampton SO9 3TN
Hampshire
ENGLAND Tel: 703-444733
Chargers (other)

Motor Appliance Corporation
22 Mercury Blvd
Chesterfield, Mo 63017
USA Tel: 314-532-3406
Chargers (on-board); Chargers (other)

Motorola Semiconductor Products, Inc
5005 E. McDowell Road
Phoenix, Arizona 85008
USA Tel: 602-244-6900
Components

Mule Battery Mfg. Co.
325 Valley St
Providence, R.I. 02908
USA Tel: 401-421-3773
Batteries (traction)

NDC Netzler & Dahlgren Co. AB
Andra Langgatan 4B
413 03 Goteborg
SWEDEN Tel: 031/42 09 10
Chargers (on-board); Chargers (other); Controllers (solid state); Drive Systems; Engineering, Research & Consultants

NV Carelec-SA
Roosveld
Landen B-3400
BELGIUM Tel: 011-88 29 11
Bikes (2 and/or 3-wheel scooters); Cars (passenger, on-the-road, less than 2000 lbs. with batteries); Controllers (solid state); Trucks (burden carriers); Trucks (on-the-road); Trucks (personnel, in-plant)

Niemand Bros., Inc
45-10 Ninety-Fourth Street
Elmhurst, N. Y. 11520
USA Tel: 212-592-2300
Components

Nissan Motor Co. Ltd.
1, Natsushima-Cho
Yokosuka
JAPAN
Cars (passenger, on-the-road, 2000 lbs. or more with batteries)

Ohio Electric Motors Division
(see Magnetics International-Ohio Elec. Motor Div.)

Onan Division-Onan Corporation
1400 73rd Ave. N E
Minneapolis, Minn. 55432
USA Tel. 612-786-6322
Alternators; Chargers (other); Generators

Otis Elevator Co
Automated Vehicle Systems
1521 Cleveland Avenue, S.W
Roanoke, Virginia 24019
USA Tel: 703-345-6792
Trucks (burden carriers); Trucks (fork lift); Trucks (personnel, in-plant); Trucks (remote control)

Otis Elevator Co
Baker Industrial Truck Div.
P.O. Box 5579
Cleveland, Ohio 44101
USA Tel: 216-651-3000
Trucks (burden carriers); Trucks (fork lift)

Otis Elevator Co.
Diversified Operations
8000 Baker Street
Cleveland, Ohio 44102
USA Tel: 216-651-3000
Buses (10 or more passengers); Cars (passenger, on-the-road, less than 2000 lbs. with batteries) Cars (passenger, on-the-road, 2000 lbs. or more with batteries); Chargers (on-board); Drive Systems; Golf Carts; Maintenance EVs (industrial/commercial type); Motors (DC, traction), Trucks (burden carriers); Trucks (fork lift); Trucks (on-the-road); Trucks (personnel, in-plant); Trucks (remote control)

Otis Elevator Co
Electrobus Division
P.O. Box 7732
Van Nuys, California 91409
USA Tel: 213-988-5630
Buses (10 or more passengers)

Otis Elevator Co.
Special Vehicle Division
P.O. Box 8600
Stockton, California 95208
USA Tel: 209-948-2751
Bikes (2 and/or 3-wheel scooters); Buses (10 or more passengers); Cars (passenger, on-the-road, less than 2000 lbs. with batteries); Cars (passenger, on-the-road, 2000 lbs. or more with batteries); Golf Carts; Maintenance EVs (home use type); Maintenance EVs (industrial/commercial type); Trucks (burden carriers); Trucks (on-the-road); Trucks (personnel, in-plant)

Otis Elevator Co
TTI Division
4700 Holly Street
Denver, Colorado 80216
USA Tel 303-399-2600
Mass Transit; Rail Systems

Palmer Industries
P O. Box 707, Union Station
Endicott, New York 13760
USA Tel 607-754-1954
Components

Pargo Inc
P.O. Box 5544
4300 Raleigh St
Charlotte, N.C. 28205
USA Tel. 704-596-6550
Golf Carts; Trucks (burden carriers); Trucks (personnel, in-plant)

Permobil Foundation
P.O. Box 90
86100 Timra
SWEDEN
Wheelchairs & Special one-person EVs (for handicapped persons)

Petro-Electric Motors, Ltd.
342 Madison Avenue
New York, N. Y. 10017
USA Tel. 212-986-3173
Buses (10 or more passengers); Cars (passenger, on-the-road, 2000 lbs. or more with batteries); Drive Systems; Engineering, Research & Consultants, Mass Transit; Trucks (on-the-road)

Pioneer Engineering & Manufacturing Co.
2500 E. Nine Mile Rd.
Warren, Mich. 48091
USA Tel. 313-755-4400
Engineering, Research & Consultants

Pluskota Electric Co
11637 So Mayfield Ave
Alsip Industrial District
Worth, Ill. 60482
USA Tel 312-597-0200
Chargers (on-board), Chargers (other); Generators

H.K Porter Co , Inc
1401 W. Market Street
Warren, Ohio 44485
USA Tel. 216-399-3651
Brushes (motor); Generators; Motors (DC, traction)

Power Applications, Inc.
581 W. Merrick Road
Valley Stream, New York 11580
USA Tel: 516-872-6336
Engineering, Research & Consultants

Power-Ped, Inc
2100 E. Admiral Drive
Virginia Beach, Virginia 23451
USA Tel 804-481-6897
Cars (passenger, on-the-road, less than 2000 lbs., with batteries)

PowerTech, Incorporated
9 Baker Court
Clifton, New Jersey 07011
USA Tel 201-478-6205
Components

Power Technology, Inc
P.O. Box 4403
Little Rock, Arkansas 72204
USA Tel 501-568-1995
Components

Prestolite Company
P.O. Box 931
Toledo, Ohio 43694
USA Tel: 419-244-2811
Alternators; Batteries (traction); Chargers (on-board); Engineering, Research & Consultants; Generators; Motors (DC, traction)

Prime Battery Mfg Co. Inc
2001 West 8th St
Anderson, Ind 46011
USA Tel 317-642-7511
Batteries (traction)

Pringle Electrical Manufacturing Co.
Fort Washington Industrial Park
Fort Washington, Pennsylvania 19034
USA Tel 215-643-0100
Components, Emergency Power Disconnect

Printed Motors Div (PMI)
(see Kollmorgen Corp - Printed Motors Div.)

Propel, Inc
210 New Market Avenue
South Plainfield, New Jersey 07080
USA Tel: 201-753-2400
Chargers (on-board); Chargers (other); Controllers (solid state); Controllers (other); Drive Systems, Engineering, Research & Consultants; Gauges (energy supply), Gauges (other); Meters; Switches (on-board type)

RPM industries
6334 Arizona Place
Los Angeles, Calif. 90045
USA Tel: 213-670-4127
Controllers (solid state)

[illegible] Inc
[illegible] Padre Faura St
Ermita, Manila
PHILIPPINES
Batteries (traction)

Randtronics, Inc.
150 Constitution Dr.
Palo Alto, Calif. 94025
USA Tel: 415-328-2640
Controllers (solid state); Drive Systems; Motors (DC, traction)

Ransome Sims & Jefferies, Ltd
Electric Truck Division
Ipswich IP3 9QG
ENGLAND Tel Ipswich 72222
Trucks (burden carriers), Trucks (fork lift), Trucks (personnel, in-plant)

The Raymonc Corporation
Greene, N.Y 13778
USA Tel 607-656-2311
Trucks (fork lift)

[illegible] Inc
P O Box 1955
Williamson, West Virginia 25661
USA Tel 304-235-2487
Chargers (other), Components, Hardware (other)

Red Diamond Battery Co
Route 6, Box 828
Garland County Industrial Park
Hot Springs, Ark 71901
USA Tel 501-262-2230
Batteries (traction)

Reg-Amp
5 Nassau Street
Rockville Centre, New York 11571
USA Tel: 516-678-6960
Chargers (on-board); Chargers (other)

Remote Control Devices
44-925 Jackson Street
Indio, California 92201
USA Tel: 714-347-2777
Golf Carts

Revolvator Company
U S Route 1 and 86th St
North Bergen, New Jersey 07047
USA Tel 201-869-1220
Trucks (burden carriers); Trucks (fork lift)

Rheinisch-Westfalisches
Elektrietatswerk
33 Heinrich-Heine-Allee
4 Dusseldorf
GERMANY
Buses (10 or more passengers), Engineering, Research & Consultants, Trucks (burden carriers), Trucks (on-the-road)

Ringsdorff Corporation
P O Box 22
East McKeesport, Pa 15035
USA Tel 412-271-8221
Brushes (motors), Hardware (rail systems), Rail Systems

Rinkmate
P O Box 8[illegible]
Port Chester New York 10573
USA Tel 914-937-0540
Maintenance EVs (industrial/commercial type)

Robicon Corporation
100 Sagamore Hill Road
Pittsburgh, Pennsylvania 15239
USA Tel 412-327-7000
Drive Systems

Rochester Instrument Systems, Inc
275 N Union Street
Rochester, New York 14605
USA Tel 716-325-5120
Controllers (solid state)

Rogers Electric Co
256 Executive Drive
Troy, Michigan 48084
USA Tel 313-585-2900
Motors (DC, Traction)

Rohr Industries, Inc
P O Box 878
Chula Vista, California 92012
USA Tel 714-426-7111
Mass Transit, Rail Systems

Rohr Monorail Systems Division
P O Box 157
Wildwood, New Jersey 08260
USA Tel 609-522-2418
Mass Transit, Rail Systems

Ross Engineering Corp
559 Westchester Drive
Campbell, California 95008
USA Tel: 408-377-4621
Chargers (on-board), Components, Controllers (other); Engineering, Research & Consultants, Meters, Switches (on-board type)

Rotron, Inc
Hasbrouck Lane
Woodstock, New York 12498
USA Tel 914-679-2401
Components; Hardware (other)

Rucker Insul-8
867 American Street
San Carlos, California 94070
USA Tel 415-591-9661
Hardware (rail systems)

S A Accumulateurs TUDOR
5981 Florival
Archennes
BELGIUM Tel: 0101 841 01
Batteries (traction); Chargers (on-board), Chargers (other)

S A E DININ
23, Avenue de la Grande Armee
75, Paris (163m3)
FRANCE
Batteries (traction)

S A E M
via Mentana 16
Monza (Milano)
ITALY
Batteries (traction)

SAEV
Sonex Recording Studio
Epsom Road, Stirling
East London
SOUTH AFRICA
Cars (passenger, on-the-road, less than 2000 lbs with batteries)

S A F T (Societe des Accumulateurs et de Traction)
156 Avenue de Metz
93230 Romainville
FRANCE Tel 845 83-47
Batteries (traction)

SAFT (United Kingdom)
Castle Works
Station Rd
Hampton, Middlesex
ENGLAND Tel 01-979-7755
Batteries (traction)

Seager Carbon Co, Inc
291 Church Street
New York, N Y 10013
USA Tel 212-925-1125
Brushes (motor)

Sebring-Vanguard, Inc.
P.O. Box 1963
Sebring, Florida 33870
USA Tel: 813-385-5116
Cars (passenger, on-the-road, less than 2000 lbs. with batteries)

SELAK GmbH
33 Heinrich-Heine Allee
4 Dusseldorf
GERMANY
Components, Connectors

Sevcon, Division of Technical Operations, Inc
Northwest Industrial Park
Burlington, Massachusetts 01803
USA Tel 617-272-2000
Controllers (solid state), Controllers (other), Engineering, Research & Consultants, Hardware (other)

Sevcon Engineering Ltd
Queensway
Team Valley
Gateshead 11
ENGLAND Tel: Low Fell 878516
Controllers (solid state), Controllers (other), Engineering, Research & Consultants, Hardware (other)

Simon Battery & Research Corp.
3040 Bigelow Boulevard
Pittsburgh, Pennsylvania 15219
USA Tel: 412-621-1810
Batteries (traction)

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Bureaux et Usine 154,
Rue Leon Blum,
Villeurbanne (Rhone)
FRANCE
Trucks (on-the-road)

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ENGLAND
Tel Newcastle upon Tyne
(STD Code 0632) 87 1311/4
Maintenance EVs (industrial commercial type), Trucks (burden carriers); Trucks (on-the-road)

SNAPS-ELECTRO
Gen de Ceuninckstraat, 37
2800-Mechelen
BELGIUM Tel: 15-21 16.15
Controllers (solid state); Engineering, Research & Consultants

Sociedad Espanola del Acumulador
Tudor, S.A
Gaztambide, 49
Madrid, 15
SPAIN Tel 449 23 12-243 65 00
Batteries (traction); Chargers (on-board), Chargers (other), Engineering, Research & Consultants

Societe Bertin & Cie
B P No 3
78 Plaisir
FRANCE
Bikes (2 and/or 3-wheel scooters)

Societe de l'Accumulateiur Fulmen
18 Quai de Clichy
Clichy (Seine)
FRANCE
Batteries (traction)

Solo Kleinmotoren GmbH
P.O Box 464
Burlington, Ontario
CANADA Tel 416-528-3704
Bikes (2 and/or 3-wheel scooters)

Solo Kleinmotoren GmbH
P O Box 20
D-7032 Sindelfingen 6
WEST GERMANY
Tel (Boeblingen-07031) 8.21 91-5
Bikes (2 and/or 3-wheel scooters)

South Wind Division
(see Stewart Warner Corp.-
South Wind Div)

Southern Carbon Brush Co., Inc
2711 S Second Street
St Louis, Missouri 63118
USA Tel 314-771-4060
Brushes (motor)

Spykstaal B V
P O. Box 9
Spijkenisse
NETHERLANDS Tel 0 1880 12266
Cars (passenger, on-the-road, less than 2000 lbs with batteries); Trucks (burden carriers); Trucks (on-the-road); Trucks (personnel, in-plant)

Standard Electric Co. Inc
P O Box 18127
San Antonio, Tex. 78218
USA
Batteries (traction)

Standard Storage Battery Co.
869 Hersey Street
St Paul, Minn 55114
USA Tel: 612-646-2707
Batteries (traction)

Stewart Warner Corporation
South Wind Division
1514 Drover Street
Indianapolis, Indiana 46221
USA Tel 317-632-8411
Hardware (other), Heaters

Stremel Engineering Co
400 Bancroft Road
Walnut Creek, California 94598
USA Tel 415-935-5052
Bikes (2 and 'or 3-wheel scooters); Engineering, Research & Consultants

Stuart Elektrowagon
1900 W Main St
Ionia, Michigan 48846
USA Tel: 616-527-9220
Cars, passenger (on-the-road, less than 2000 lbs. with batteries); Engineering, Research & Consultants; Trucks (on-the-road)

Sun Chemical Corporation
Facile Division
185 Sixth Avenue
Paterson, New Jersey 07524
USA Tel. 201-684-1000
Battery Separators

Sunward Corporation
21414 Chase Street
Canoga Park, California 91304
USA Tel: 213-882-3330
Bikes (2 and/or 3-wheel scooters); Components

Surrette Storage Battery Co., Inc.
Springhill, N S
CANADA Tel 902-597-3767
Batteries (traction)

Surrette Storage Battery Co., Inc
P.O. Box 711
Salem, Massachusetts 01970
USA Tel: 617-745-4444
Batteries (traction)

TUC Industries, Inc
P O Box 237
Chester, Connecticut 06412
USA Tel: 203-526-9505
Chargers (on-board); Chargers (other); Gauges (energy supply); Gauges (other)

Tapeswitch Corp. of America
320 Broad Hollow Road
Farmingdale, New York 11735
USA Tel: 516-694-6312
Hardware (other)

Taylor-Dunn
2114 W Ball Rd
Anaheim, Calif 92804
USA Tel: 714-956-4040
Golf Carts, Trucks (burden carriers). Trucks (personnel, in-plant)

Techniques Electriques Jarret
31 Rue Chardon-Lagache
Paris 16
FRANCE
Drive Systems

Teilhol Electricque
Societe des Etablissements Teilhol
63120 Courpiere
FRANCE
Cars (passenger, on-the-road, less than 2000 lbs with batteries)

Teledyne Battery Products
P.O. Box 431
Redlands, Calif 92373
USA Tel: 714-793-3131
Batteries (traction)

G H. Tennant Co
701 N Lilac Drive
Minneapolis, Minn. 55422
USA Tel: 612-540-1200
Maintenance EVs (industrial/ commercial type)

Texas Battery Co
P O Box 645
Cleburne, Tex 76031
USA
Batteries (traction)

Texas Instruments, Inc
34 Forest Street
Attleboro, Massachusetts 02703
USA Tel 617-222-2800
Components; Switches (on-board)

Texon, Inc.
Canal Street
South Hadley, Mass. 01075
USA Tel: 413-536-1610
Battery Separators

George H. Thomas Industries, Inc
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Lansing, Michigan 48912
USA Tel: 517-485-7115
Chargers (on-board); Controllers (solid state)

Thornton Power Systems, Inc.
87 Beaver Street
Waltham, Massachusetts 02154
USA Tel: 617-899-1400
Controllers (solid state); Controllers (other)

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Sub. of Caterpillar Tractor Co.
7111 Tyler Blvd
Mentor, Ohio 44060
USA Tel: 216-255-5611
Trucks (fork lift)

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Aki-Gun, Hiroshima
JAPAN
Bikes (2 and/or 3-wheel scooters), Cars, (passenger, on-the-road, less than 2000 lbs with batteries)

Toyota Motor Distributors, Inc.
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12515 Hawthorne Blvd
Torrance, Calif. 90503
USA Tel: 213-320-5770
Trucks (fork lift)

Traction Propulsion, Inc
P.O Box 9056
Austin, Texas 78766
USA Tel: 512-441-0000
Transmissions

Trans Drive
6020 Centreville Road
Centreville, Virginia 22020
USA Tel: 703-830-8599
Engineering, Research & Consultants; Hardware (rail systems); Rail Systems

Triple-A-Specialty Co
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Chicago, Illinois 60638
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Santa Fe Springs, Calif 90670
USA
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USA Tel 213-378-8947
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Montreal H2S 2X3
Quebec
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South Hadley Falls, Mass 01075
USA Tel: 413-533-4460
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Roman Road
Mountessing
Brentwood, Essex
ENGLAND Tel Ingatestone 2000
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Arno (Pisa)
ITALY
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Vantage Boats
5390 Cherokee Avenue
Alexandria, Virginia 22312
USA Tel: 703-354-8383
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3000 Hannover-Stocken
Stockener Strabe 351
GERMANY
Batteries (traction)

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Suite 236-240
Willowdale, Ontario
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Batteries (traction)

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3205 Udall St., Point Loma
San Diego, California 92106
USA Tel: 714-453-8894
Engineering, Research & Consultants

Voiture Electronique
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Paris 16
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Abteilungsleiter Forschung 6
318 Wolfsburg
GERMANY
Trucks (on-the-road)

Voltmaster Company
P.O Box 388
Corydon, Iowa 50060
USA Tel 515-872-0244
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Alan M Voorhees & Associates
Westgate Research Park
McLean, Virginia 22101
USA Tel 703-893-4310
Engineering, Research & Consultants

Vought Aeronautics Co
P O Box 5003
Dallas, Texas 75222
USA Tel: 214-742-9555
Mass Transit, Rail Systems

W & E Vehicles
Harlescott
Shrewbury
ENGLAND Tel Shrewbury 52631
Maintenance EVs (industrial/commercial type); Trucks (burden carriers); Trucks (on-the-road), Trucks (personnel, in-plant)

Ward Leonard Electric Co., Inc.
31 South Street
Mount Vernon, New York 10550
USA Tel: 914-664-1000
Components

C H Waterman Industries
White Pond Road
Athol, Massachusetts 01331
USA Tel. 617-249-6801
Cars (passenger, on-the-road, 2000 lbs or more with batteries) Trucks (on-the-road); Wheelchairs & special one-person EVs for handicapped persons)

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9000 Alpine Avenue
Detroit, Michigan 48204
USA Tel 313-933-8000
Engineering, Research & Consultants; Trucks (remote control)

West Bend Equipment Corp
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300 Water Street
West Bend, Wisc 53095
USA Tel: 414-334-5561
Trucks (fork lift)

Westcode Limited
282 Belfield Road
Rexdale, Ontario M9W 1H5
CANADA Tel 416-677-5881
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Western Batteries, Inc
11155 S W Denny Road
Beaverton, Oregon 97005
USA Tel 503-644-3138
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Westinghouse Brake & Signal Co Ltd
Chippenham
Wiltshire SN15 1JD
ENGLAND Tel. Chippenham 4141
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Springfield, Mass 01101
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Motors (DC, traction)

Westinghouse Electric Corp.
875 Greentree Road, Bldg. 8-4th Fl.
Pittsburgh, Pennsylvania 15220
USA Tel: 412-928-4651
Brushes (motor); Chargers (on-board); Chargers (other); Components; Golf Carts; Trucks (burden carriers); Trucks (personnel, in-plant)

Westinghouse Electric Corp.
Electric Vehicles
P O Box 712
Redlands, California 92373
USA Tel 714-793-2891
Golf Carts, Maintenance EVs (industrial/commercial type); Trucks (burden carriers), Trucks (personnel, in-plant)

Wheel Horse Products, Inc
Bldg 702, Corporations Park
Scotia, New York 12302
USA
Maintenance EVs (home use type)

Yardney Electric Corporation
82 Mechanic Street
Pawcatuck, Connecticut 02891
USA Tel 203-599-1100
Batteries (traction), Components

Yardney Electric Corporation
500 Sagamore Parkway West
West Lafayette, Indiana 47906
USA Tel. 317-463-7595
Batteries (traction), Components

Young Windows, Inc
Brook & Colwell Roads
Conshohocken, Penna 19428
USA Tel 215-828-5422
Components, Hardware (other)

Yuasa Battery (America) Ltd.
8108 Freestone Avenue
Santa Fe Springs, Calif 90670
USA
Batteries (traction)

Yuasa Battery Co., Ltd
11-12, 2-Chome.
Higashi-Shinbashi, Minato-Ku
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JAPAN Tel (03) 437-2411
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Prestolite Company

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Accumulatorenfabriken Wilhelm Hagen AG
Accumulatorenwerk Hoppecke
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Acme Battery Mfg Co
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Battery Systems, Inc
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Chloride Batteries Australia, Ltd
Chloride Group Limited
Chloride India Limited
Chloride Industrial Batteries, Ltd
Chloride S.A. (Pty) Ltd
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Electric Power Engineering Co (B'ham) Ltd
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Electrona Limited
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Fabbrica Accumulatori Uranio SpA
Fabbrica Accumulatori York SpA
Fabbrica Italiana Magneta Marelli
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Prestolite Company
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S A E M
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Societe del l'Accumulateiur Fulmen
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Standard Storage Battery Co
Surrette Storage Battery Co., Inc., Canada
Surrette Storage Battery Co., Inc., USA
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Texas Battery Co.
Trojan Battery Co.
VARTA Batterie AG
VARTA BATTERIES, LTD
Voltmaster Company
Western Batteries, Inc
Yardney Electric Corp , Connecticut
Yardney Electric Corp , Indiana
Yuasa Battery (America) Ltd.
Yuasa Battery Co., Ltd

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Evans Products Company
W. R. Grace & Company
Sun Chemical Corp., Facile Division
Texon, Inc.
Yuasa Battery Co., Ltd

BIKES (2 and/or 3-wheel scooters)

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Canadian Korefine Company, Ltd
Corbin-Gentry, Inc.
El Bilar AB
Electricycle
Ikecycle Corp., Radford Co
James Research Co.
Joggers, Inc.
Kysor of Cadillac
Lamb Electric Tricycles
Lyman Metal Products
Marathon Golf Car, Ltd
N V CARELEC - SA
Otis Elevator Co. - Special Vehicle Division
Societe Bertin & Cie
Solo Kleinmotoren GmbH, Canada
Solo Kleinmotoren GmbH, West Germany
Stremel Engineering Co.
Sunward Corporation
Toyo-Kogyo Co., Ltd
Voiture Electronique

BOATS, electric

Branson Boat Company
Daste Electric Enterprises, Inc.
Duffield Marine
Undersea Graphics, Inc
Vantage Boats

BRAKES

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Gerdes Products Company
Lansing Bagnall, Ltd
Mercury Clutch Div. of ASPRO, Inc.
Westcode Limited

BRUSHES, motors

Robert Bosch Corporation
Intrupa
Lansing Bagnall, Ltd
Morganite, Incorporated
H. K. Porter Co., Inc
Ringsdorff Corporation
Seager Carbon Co., Inc.
Southern Carbon Brush Co., Inc
Westinghouse Electric Corp.

BUSES, 10 or more passengers

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Chloride Industrial Batteries, Ltd
The Chubu Electric Power Co., Inc
Crompton Electricars, Ltd
Daimler-Benz AG
Elbil A/S
The Kansai Electric Power Co., Inc.
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Otis Elevator Co. - Electrobus Division
Otis Elevator Co. - Special Vehicle Division
Petro-Electric Motors, Ltd
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CARS, passenger, on-the-road, less than 2000 lbs. with batteries

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Evelec S.A
Gurgel Industria e Commercio de Vehiculos Ltda
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Sebring-Vanguard, Inc.
Spykstaal B.V
Stuart Elektrowagon
Teilhol Electricque
Toyo-Kogyo Co , Ltd
Urbanina S P A
Voiture Electronique

CARS, passenger, on-the-road, 2000 lbs. or more with batteries

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Daihatsu Kogyo Co., Inc
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Electric Vehicle Associates, Inc
Enfield Automotive Ltd
Evelec S A
Hellectric
McKee Engineering Corporation
Monark-Crescent AB
Nissan Motor Co., Ltd

Otis Elevator Co - Diversified Operations
Otis Elevator Co.- Special Vehicle Division
Petro-Electric Motors, Ltd
C H Waterman Industries

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Robert Bosch Corporation
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Canadian Korefine Company, Ltd
Christie Electric Corp
Controltek, Inc
Dunlop Batteries Australia
Electric Fuel Propulsion Corp
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Electric Vehicle Associates, Inc
Exide & Kathanode Batteries
Fox Products Co
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Yuasa Battery Co., Ltd

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Chloride Industrial Batteries, Ltd
Christie Electric Corp
Controltek, Inc
Dunlop Batteries Australia
ESB Incorporated
Electric Fuel Propulsion Corp
Exide & Kathanode Batteries
Fox Products Co
Furukawa Battery Co , Ltd
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Cableform, Limited
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Intrupa
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SELAK GmbH
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Pioneer Engineering & Manufacturing Co
Power Applications, Inc.
Prestolite Company
Propel, Inc
Rheinisch-Westfalisches Elektrietatswerk
Ross Engineering Corp
SEVCON, Div. of Technical Operations, Inc
Sevcon Engineering Ltd
SNAPS-ELECTRO
Sociedad Espanola del Acumulador Tudor, S.A.
Stremel Engineering Co
Stuart Elektrowagon
TransDrive
Tympanium Corporation
U S Flywheels, Inc

VHICO - Von Heck International Co.
Alan M. Voorhees & Associates
Jervis B. Webb Company

GAUGES, energy supply

Accumulatorenfabriken Wilhelm Hagen AG
Controltek, Inc
Curtis Instruments, Inc.
Electric Vehicle Systems
Engler Instrument Company
Flight Systems, Inc.
Flight Systems, Ltd.
Propel, Inc.
TUC Industries, Inc
Unican Electrochemical Products, Ltd.

GAUGES, other

Beede Elect. Inst. Co., Inc
Kollmorgen Corp. - Inland Motor Div.
Propel, Inc.
TUC Industries, Inc

GENERATORS

ASEA International
Robert Bosch Corporation
CAV Limited
Fidelity Electric Co., Inc.
Kollmorgen Corp. - Printed Motors Div (PMI)
Onan Division - Onan Corporation
Pluskota Electric Co
H. K. Porter Co., Inc
Prestolite Company

GOLF CARTS

Auranthetic Corporation
Canadian Korefine Company, Ltd
Candlish Equipment, Ltd.
Citation Manufacturing Co.
Club Car, Inc.
Compass Industries, Inc.
Cushman - Outboard Marine Corp.
E-Z-GO
Eagle-Picher
Electric Carrier Corporation
Electric Fuel Propulsion Corp.
Evelec S.A
Flagmaster, Inc.
Harbilt Electric Trucks & Vehicles
Joggers, Inc
Lektro Inc
Marathon Golf Car, Ltd.
Otis Elevator Co. - Diversified Operations
Otis Elevator Co. - Special Vehicle Division
Pargo, Inc
Remote Control Devices
Taylor-Dunn
Urbania S P A
Westinghouse Electric Corp.

HARDWARE, rail systems

ASEA International
The Garrett Corporation
I-T-E Imperial Corporation
Ringsdorff Corporation
Rucker Insul-8
TransDrive
Westcode Limited

HARDWARE, other

FMC Corporation
Monroe Auto Equipment Co.
Rectron, Inc
Rotron, Inc
SEVCON, Div. of Technical Operations, Inc

Sevcon Engineering, Ltd.
Stewart Warner Corp. - South Wind Div
Tapeswitch Corp. of America
Union Engineering Corp.
Young Windows, Inc

HEATERS

Hunter Manufacturing Co
Stewart Warner Corp. - South Wind Div.

MAINTENANCE EVs, home use type

Avco New Idea Farm Equipment
Battery Power Unit Corp.
John Deere Company
El Bilar AB
Electric Carrier Corporation
Marathon Golf Car, Ltd.
Otis Elevator Co. - Special Vehicle Division
Wheel Horse Products, Inc.

MAINTENANCE EVs, industrial/commercial type

AM General Corporation
Advance Floor Machine Co.
American-Lincoln - Div. of Scott & Fetzer Co.
Avco New Idea Farm Equipment
Battery Power Unit Corp.
Canada Power Skoot, Ltd
Canadian Korefine Company, Ltd
Candlish Equipment, Ltd.
Clarke Div. - Clarke-Gravely Corp.
Crompton Electricars, Ltd
Electric Carrier Corporation
Harbilt Electric Trucks & Vehicles
Joggers, Inc.
Lansing Bagnall (Canada)
Lansing Bagnall, Ltd
Lawlor Industries, Inc.
Lektro, Inc.
R. A. Lister & Co., Ltd.
Marathon Golf Car, Ltd.
Otis Elevator Co. - Diversified Operations
Otis Elevator Co. - Special Vehicle Division
Rinkmate
Smith's Electric Vehicles Limited
G. H. Tennant Co.
Westinghouse Electric Corp. - Electric Vehicles
Yuasa Battery Co., Ltd.

MASS TRANSIT

ASEA International
Battronic Truck Corp.
The Boeing Co. - Vertol Div
Ford Motor Co. - Transportation Systems
The Garrett Corporation
General Electric Co
Grumman Aerospace - Advanced Surface Transportation
Joggers, Inc.
Messerschmitt-Boelkow-Blohm GmbH - Advanced Transport Systems
Otis Elevator Co. - TTI Division
Petro-Electric Motors, Ltd.
Rohr Industries, Inc.
Rohr Monorail Systems Division
Vought Aeronautics Co.
W & E Vehicles

METERS

Beede Elect. Inst. Co., Inc.
Controltek, Inc.
Intrupa
Propel, Inc
Ross Engineering Corp

MOTORS, DC, Traction

ASEA International
Allis Chalmers Corp - Motor and Generator Div
Ambac Industries, Inc. - American Bosch Electrical Products Div
Applied Motors, Inc
Robert Bosch Corporation
CAV Limited
Electric Vehicle Associates, Inc
Electro Dynamic Construction Co., Ltd
Fidelity Electric Co., Inc
General Electric Co
General Electric Co. - DC Motor & Generator Products Dept
Gould, Inc. - Century Electric Division
Kollmorgen Corp. - Inland Motor Div.
Kollmorgen Corp. - Printed Motors Div (PMI)
Lansing Bagnall, Ltd
Lawnel Corporation
Magnetics International - Ohio Electric Motors Div
Otis Elevator Co. - Diversified Operations
H. K. Porter Co., Inc
Prestolite Company
Randtronics, Inc.
Rogers Electric Co
Westinghouse Electric Corp.

RAIL SYSTEMS

ASEA International
The Boeing Co. - Vertol Div
Ford Motor Co. - Transportation Systems
The Garrett Systems
General Electric Co
Grumman Aerospace - Advanced Surface Transportation
Messerschmitt-Boelkow-Blohm GmbH - Advanced Transport Systems
Otis Elevator Co. - TTI Division
Ringsdorff Corporation
Rohr Industries, Inc
Rohr Monorail Systems Division
TransDrive
Vought Aeronautics

SWITCHES, on-board type

Anderson Power Products, Inc.
Robert Bosch Corporation
CAV Limited
General Electric Co. - Industrial Control Products Dept
Brad Harrison Company
I-T-E Imperial Corporation
Intrupa
Propel Inc
Ross Engineering Corp
Texas Instruments, Inc

TIRES

Firestone Tire & Rubber Co
McCreary Tire & Rubber Co

TRANSMISSIONS

Dana Corporation
Dana Corporation - Spicer Clutch Division
Electric Motion Control Corp. Intl
Joseph Lucas (Sales & Service) Ltd.
McKee Engineering Corporation
Traction Propulsion, Inc.

TRUCKS, burden carriers

Blue Giant Equipment Corp
Candlish Equipment, Ltd
Clayton Equipment Co , Ltd
Cleco Electric Industries, Ltd
Club Car, Inc
Coventry Climax Engines, Ltd.
Crompton Electricars, Ltd
Cushman - Outboard Marine Corp.
Douglas Electric Trucks
Electric Carrier Corporation
Gardner Manufacturing Co
Gough Industrial Trucks, Ltd
Harbilt Electric Trucks & Vehicles
Iso-Speedic Company, Ltd
Lansing Bagnall (Canada)
Lansing Bagnall, Ltd
Lektro, Inc
R A. Lister & Co , Ltd
Montgomerie Reid, Ltd
N V CARELEC - SA
Otis Elevator Co - Automated Vehicle Systems
Otis Elevator Co - Baker Industrial Truck Div
Otis Elevator Co - Diversified Operations
Otis Elevator Co. - Special Vehicle Division
Pargo, Inc
Ransome Sims & Jefferies, Ltd - Electric Truck Division
Revolvator Company
Rheinisch-Westfalisches Elektrietatswerk
Smith's Electric Vehicles, Limited
Spykstaal B V
Taylor-Dunn
G A Upson Electrical Limited
W & E Vehicles
Westinghouse Electric Corp.

TRUCKS, fork lift

Allis-Chalmers Corp. - Industrial Truck Div
Barrett Electronics Corp
Big Joe Manufacturing Co
Blue Giant Equipment Corp
Clark Equipment Co. - Industrial Truck Div.
Conveyancer Fork Trucks, Ltd
Crown Controls Corporation
Drexel Industries, Inc
Eaton Corp
Hyster Company
Lansing Bagnall (Canada)
Lansing Bagnall, Ltd
Lawnel Corporation
Lectro-Lift, Inc
Lektro, Inc
Otis Elevator Co. - Automated Vehicle Systems
Otis Elevator Co - Baker Industrial Truck Div
Otis Elevator Co - Diversified Operations
Ransome Sims & Jefferies, Ltd - Electric Truck Div
The Raymond Corporation
Revolvator Company
Towmotor Corp
Toyota Motor Distributors, Inc
G. A. Upson Electrical Limited
West Bend Equipment Corp

TRUCKS, on-the-road

AM General Corporation
Battronic Truck Corp.
Clayton Equipment Co , Ltd
Club Car, Inc
Crompton Electricars, Ltd
Elbil A S
Harbilt Electric Trucks & Vehicles
Iso-Speedic Company, Ltd
Messerschmitt-Boelkow-Blohm GmbH Advanced Transport Systems
Montgomerie Reid, Ltd
N V CARELEC - SA
Otis Elevator Co - Diversified Operations
Otis Elevator Co. - Special Vehicle Division
Petro-Electric Motors, Ltd
Rheinisch-Westfalisches Elektrietatswerk
SITA, Siege Social
Smith's Electric Vehicles, Limited
Spykstaal B V
Stuart Elektrowagon
G A Upson Electrical Limited
Volkswagen Werk AG
W & E Vehicles
C H. Waterman Industries

TRUCKS, personnel, in-plant

Auranthetic Corporation
Battery Power Unit Corp
Battronic Truck Corp.
Canada Power Skoot Ltd
Candlish Equipment, Ltd
Club Car, Inc
Crompton Electricars, Ltd
Douglas Electric Trucks
Electric Carrier Corporation
Flagmaster, Inc
Harbilt Electric Trucks & Vehicles
Iso-Speedic Company, Ltd
James Research Co
Joggers, Inc
Lansing Bagnall (Canada)
Lansing Bagnall, Ltd
Lektro, Inc.
R A. Lister & Co., Ltd
Marathon Golf Car, Ltd.
Mars Industries, Inc
Montgomerie Reid, Ltd
N V CARELEC - SA
Otis Elevator Co. - Automated Vehicle Systems
Otis Elevator Co - Diversified Operations
Otis Elevator Co. - Special Vehicle Division
Pargo, Inc
Ransome Sims & Jefferies, Ltd. - Electric Truck Div
Spykstaal B V
Taylor-Dunn
G. A. Upson Electrical Limited
Voiture Electronique
W & E Vehicles
Westinghouse Electric Corp.

TRUCKS, remote control

Control Engineering Company
Otis Elevator Co. - Automated Vehicle Systems
Otis Elevator Co. - Diversified Operations
Jervis B Webb Company

WHEELCHAIRS & SPECIAL ONE-PERSON EVs for handicapped persons

Baltric, Ltd
Battery Power Unit Corp.
Canadian Korefine Company, Ltd.
Compass Industries, Inc
Grumman Aerospace - Advanced Surface Transportation
Harbilt Electric Trucks & Vehicles
Ikecycle Corp , Radford Co
Kinetics, Inc
Permobil Foundation
C H Waterman Industries

ALPHABETICAL LISTING OF EV-RELATED ASSOCIATIONS, CLUBS, SOCIETIES, etc.

American Public Power Association
2600 Virginia Avenue, N.W
Washington D.C. 20037
USA Tel: 202-333-9200

Australian Lead Development Association
95 Collins Street
Melbourne, Victoria 3000
AUSTRALIA

Battery Council International
1801 Murchison Drive
Burlingame, California 94010
USA Tel: 415-692-1545

Battery Vehicle Society
238 South Coast Road
Peacehaven
Sussex, BN9 8JS
ENGLAND

Committee For The Handicapped
1146-16th Street, N.W
Washington, D.C. 20036
USA Tel: 202-223-4450

Copper & Brass Information Center
North House, 321 Kent Street
Sydney, N.S.W. 2000
AUSTRALIA

Copper Development Association, Inc.
405 Lexington Avenue
New York, N.Y. 10017
USA Tel: 212-867-6500

Electric Auto Association
1249 Lane Street
Belmont, California 94002
USA Tel: 415-591-6698

Electric Auto Association
1372 Dentwood Drive
San Jose, California 95118
USA Tel: 408-266-2360

Electric Vehicle Council
90 Park Avenue
New York, N. Y. 10016
USA Tel: 212-573-8700

Electric Vehicle Council of Central Africa
6 Plympton Road
Chadcombe, Hatfield
Salisbury S.E. 57
RHODESIA Tel: 55304

Electric Vehicle News
P. O. Box 533
Westport, Connecticut 06880
USA Tel: 203-226-4600

Electrical Apparatus Service Association, Inc.
1331 Baur Boulevard
St. Louis, Missouri 63132
USA Tel: 314-993-2220

Electrical Vehicle Association Of Great Britain, Ltd.
Trafalgar Buildings
1 Charing Cross
London S.W. 1
ENGLAND Tel: 01-930-6757

Farm Electrification Council
Box 1008
Oak Brook, Illinois 60523
USA Tel: 312-654-0810

Independent Battery Manufacturers Association, Inc
100 Larchwood Drive
Largo, Florida 33540
USA Tel: 813-584-5540

Indian Lead Zinc Information Center
B5-27 Safdarjung Enclave
New Delhi 16
INDIA

Institute For Rapid Transit
1612 K Street, N W
Washington, D.C. 20006
USA Tel: 202-638-3157

Institute of Electrical & Electronics Engineers
345 East 47th Street
New York, N.Y. 10017
USA Tel: 212-752-6800

International Lead Zinc Research Organization, Inc
292 Madison Avenue
New York, N. Y. 10017
USA Tel: 212-532-2373

Japan Automobile Manufacturing Association
4-1 Chome Otemachi, Chiyoda-Ku
Tokyo
JAPAN

Japan Automobile Manufacturing Association
30 East 42nd Street
New York, N. Y. 10017
USA

Japan Electric Association
3-1 Chome Yuraku-Cho, Chiyoda-Ku
Tokyo
JAPAN

Japan Lead Zinc Development Association
No. 1-3-6 Uchisalwaicho, Chiyoda-Ku
Tokyo
JAPAN

Lead Development Association
34 Berkeley Square
London W1
ENGLAND

Lead Industries Association, Inc
292 Madison Avenue
New York, N. Y. 10017
USA Tel: 212-679-6020

The Material Handling Institute, Inc.
1326 Freeport Road
Pittsburgh, Pennsylvania 15238
USA Tel: 412-782-1624

Motor Vehicle Manufacturers Assn. of U.S
320 New Center Building
Detroit, Michigan 48202
USA Tel: 313-872-4311

National Association of Fleet Administrators
22 E. 42nd Street
New York, N. Y. 10017
USA Tel: 212-682-7130

National Electrical Manufacturers Association
155 E. 44th Street
New York, N. Y. 10017
USA Tel: 212-682-1500

National Rural Electrification Cooperative Assn
2000 Florida Avenue, N.W.
Washington, D.C. 20009
USA Tel: 202-265-7400

National Safety Council
425 N. Michigan Avenue
Chicago, Illinois 60611
USA Tel: 312-527-4800

National Science Foundation
1800 G St., N.W
Washington, D.C. 20001
USA Tel: 202-655-4000

New Zealand Battery Electric Vehicle Club
14 Hospital Road
Kawakawa
NEW ZEALAND Tel: 482 Kawakawa

Recreational Vehicle Institute
2720 Des Plaines Avenue
Des Plaines, Illinois 60018
USA Tel: 312-299-7141

Scandinavian Lead Zinc Association
22 Sturegatan
Stockholm
SWEDEN

Society of Automotive Engineers, Inc.
18121 E. Eight Mile Road
East Detroit, Michigan 48021
USA Tel: 313-773-0703

Society of Automotive Engineers, Inc.
2 Pennsylvania Plaza
New York, N. Y. 10012
USA Tel: 212-594-5700

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